2nd International Conference on ESAR „Expert Symposium on Accident Research“

Berichte der
Bundesanstalt für Straßenwesen

Fahrzeugtechnik Heft F 61

2nd International Conference on ESAR „Expert Symposium on Accident Research“

Reports on the ESAR-Conference on 1st/2nd September 2006 at Hannover Medical School

organized by

Accident Research Unit at Hannover Medical School (MHH)
Federal Highway Research Institute, Bergisch Gladbach (BASt)
Research Association of German Car Manufacturers, Frankfurt/M., (FAT)
University of Technology, Dresden

Berichte der Bundesanstalt für Straßenwesen

Fahrzeugtechnik Heft F 61

Die Bundesanstalt für Straßenwesen veröffentlicht ihre Arbeits- und Forschungsergebnisse in der Schriftenreihe **Berichte der Bundesanstalt für Straßenwesen**. Die Reihe besteht aus folgenden Unterreihen:

A - Allgemeines
B - Brücken- und Ingenieurbau
F - Fahrzeugtechnik
M - Mensch und Sicherheit
S - Straßenbau
V - Verkehrstechnik

Es wird darauf hingewiesen, dass die unter dem Namen der Verfasser veröffentlichten Berichte nicht in jedem Fall die Ansicht des Herausgebers wiedergeben.

Die Hefte der Schriftenreihe **Berichte der Bundesanstalt für Straßenwesen** können direkt beim Wirtschaftsverlag NW,
Verlag für neue Wissenschaft GmbH,
Bgm.-Smidt-Str. 74-76,
D-27568 Bremerhaven,
Telefon (04 71) 9 45 44 - 0, bezogen werden.

Über die Forschungsergebnisse und ihre Veröffentlichungen wird in Kurzform im Informationsdienst **BASt-Info** berichtet. Dieser Dienst wird kostenlos abgegeben; Interessenten wenden sich bitte an die Bundesanstalt für Straßenwesen, Referat Öffentlichkeitsarbeit.

Impressum

Herausgeber
Bundesanstalt für Straßenwesen
Brüderstraße 53, D-51427 Bergisch Gladbach
Telefon: (0 22 04) 43 - 0
Telefax: (0 22 04) 43 - 674

Redaktion
Referat Öffentlichkeitsarbeit

Druck und Verlag
Wirtschaftsverlag NW
Verlag für neue Wissenschaft GmbH
Postfach 10 11 10, D-27511 Bremerhaven
Telefon: (04 71) 9 45 44 - 0
Telefax: (04 71) 9 45 44 77
Email: vertrieb@nw-verlag.de
Internet: www.nw-verlag.de

ISSN 0943-9307
ISBN 978-3-86509-644-9

Bergisch Gladbach, März 2007

Kurzfassung – Abstract

2. Internationale Konferenz ESAR, „Expertensymposium Accident Research“

An der Medizinischen Hochschule Hannover fand im September 2006 zum zweiten Mal die ESAR-Konferenz statt. Wieder einmal wurde mit der diesjährigen Konferenz der aktuelle Stand der Forschung auf dem Gebiet der Unfallerhebungen vor Ort, der sog. In-Depth Accident Studies, präsentiert. ESAR steht für „Expert Symposium on Accident Research“ und soll eine Plattform für Wissenschaftler bieten, ihre erarbeiteten Ergebnisse einem internationalen Gremium von Wissenschaftlern, Behörden- und Industrievertretern darzustellen und zu diskutieren, um eine Implementierung geeigneter Methoden und Maßnahmen zur Unfall- und Verletzungsvermeidung zu erzielen. Die alle 2 Jahre stattfindende Konferenz soll als Ergänzung und nicht als Konkurrenz zu anderen bestehenden Fachkonferenzen der Fahrzeugtechnik, der Unfallmedizin und Verkehrspsychologie angesehen werden.

Die diesjährige Konferenz bestätigt das Interesse durch die Anzahl der Teilnehmer, Variationen der wissenschaftlichen Arbeiten und der interdisziplinären Vortragenden von Medizin, Psychologie und Ingenieurwissenschaften. Mehr als 100 Teilnehmer aus 13 Ländern und 4 verschiedenen Kontinenten kamen nach Hannover. Damit kann der Anspruch an ein hohes Maß an Verkehrssicherheit, welcher zweifellos für Europa, USA und Australien schon jetzt gilt, auch auf Länder der Dritten Welt, wie Asien und Afrika, mit noch bestehendem hohem Verletzungsrisiko, auch gezielt übertragen werden.

2nd International Conference on ESAR, “Expert Symposium on Accident Research”

The second ESAR Conference took place at the Medical University Hannover. This year conference presents the current state of affairs of relevant research activities in the field of in-depth investigations. The first conference on ESAR (Expert Symposium on Accident Research) was established in 2004. It is planned to hold ESAR every two years. Hannover seems to be the right place for this conference concerning the fact that the first in-depth research team was found here in the year 1973 and comprehensive studies on accident analysis were spread out from here around the world continuously.

This year conference topped all expectations in terms of the numbers of participants, in the variety of papers and the interdisciplinary of presenters from medical, psychological and engineering background. More than 100 delegates from all over the world, i.e. 13 different countries and from 4 different continents, came to Hannover, presented their results of accident investigation and discussed countermeasures for accident prevention and injury reduction. ESAR should be a platform for exchange of knowledge to find an optimized way for increase of traffic and vehicle safety by in-depth investigation and methodology. ESAR as international conference should be a platform for consideration of all nations round the world. This seems to be very important for the current situation, having high safety in the high industrial countries of Europe, US and Australia, but low safety and high injury risk in Asia and Africa.

Contents

Poster Session: Short Presentations

Session: Accident Prevention and Causation

Session: Injury Prevention and Mechanism

Welcome Addresses for the 2nd International Conference on ESAR "Expert Symposium on Accident Research"

E. Brühning

D. Bitter-Suermann

W. Hahn

E. Brühning on behalf of
President and Professor Dr.-Ing. J. Kunz
Federal Highway Research Institute,
Bergisch Gladbach, Germany

Good morning,

Ladies and Gentlemen,

First, I would like to convey the greetings of the president of the BASt, Professor Kunz, who, to his great regret, cannot be with us here and who has asked me to stand in for him.

I would like to welcome you to the 2nd International Conference on ESAR: "Expert Symposium on Accident Research".

We are very glad that Professor Otte and the other organizers are able to host the Conference for a second time at the "Hannover Medical School".

Accident Research is very important for understanding how accidents occur and what has happened to the people and the cars. Our aims are very ambitious. In Europe we want to halve the number of fatalities from 40.000 to 20.000 in the decade up to 2010.

In Germany we have achieved great success in road safety in the past 30 years. With a multiple increase in mileage and the number of vehicles, the number of traffic fatalities has been reduced in this period from more than 20.000 to 5.361 in the year 2005. This is the lowest ever recorded. In the first half of 2006 there has been a further reduction of 9%.

There are many reasons for this success. There have been clear safety-relevant changes in all areas of road safety: in road network development and the design of the road environment, in traffic engineering and control and the construction of vehicles, in driver training and safety education, in rescue service and traffic law.

For more than 30 years the traffic safety research of the Federal Highway Research Institute (the BASt) has contributed to these developments. Here, right from the start, emphasis was placed on the proper provision of accident data which also included the interdisciplinary research into causes, conditions and consequences of accidents by medical experts, vehicle technicians and traffic experts. After some years these efforts were concentrated here in Hannover and thus, for 30 years, the in-depth accident investigation on behalf of the BASt was conducted here in Hannover. Over the years, this resulted in a remarkable improvement in the quality of the data and the method of its collection. Also the quantity of the annually collected accidents was increased. Data from the "Accident Research Unit Hannover" became an indispensable basis for questions in biomechanics and passive vehicle safety. They are required for early detection of the changes in the structure of the course of accidents. The data also served as the base for investigations into active vehicle safety and for questions on the design of roads and road equipment.

In-depth accident investigation is expensive! Money-saving proposals, that after so many years one really should know everything and the money for this expensive collection of data can be better used elsewhere, could however be easily rejected by BASt.

On the contrary: because of the increasing need for data, the GIDAS project (German In-Depth Accident Study) was started in 1999. In this joint project by the Federal Highway Research Institute (BASt) and the German Association for Research on Automobile Technique (FAT), research on traffic accidents is now carried out at two places, Hannover and Dresden. The structure of this joint project is based on the experience of in-depth accident investigation here at the Medical University of Hannover. In addition to the already established team there was formed a further team at the Technical University in Dresden 7 years ago.

For the automobile industry and the Federal Highway Research Institute, the GIDAS database provides the possibility of undertaking comparisons between actual accident events and crash experiments. Vehicle structures that can cause injuries can be identified. In addition, the data is used for developing test programmes for supporting and validating computer simulations, for recognizing and estimating potential regions of future safety developments and for evaluating the vehicle safety-performance in actual accident events.

The great safety achievements of the past that I mentioned at the beginning must be continued. The German Federal Ministry for Transport, Building and Urban Affairs, in its programme for more safety in road traffic has highlighted means and ways of protecting human lives. Substantial improvement in safety with increasing mobility is also the aim of the 3rd traffic safety programme of the EU and its white book "Time for decision": 50% less traffic deaths by the year 2010 is an ambitious goal. The result of this is an international need for reliable and detailed accident data.

With this background the international orientation of this conference is especially important and for this reason I would very much like to welcome the guests from other European countries and from Africa, America, Asia and Australia.

I wish all the speakers and participants at this "2nd International Conference on ESAR" not only new ideas and practical information for more traffic safety, but also interesting discussions and fruitful contacts in the breaks and at the conference dinner tonight.

My special thanks go to Professor Otte and his staff who initiated and organized this conference.

Finally, I wish the 2nd ESAR conference much success.

D. Bitter-Suermann
Hannover Medical School, Germany

Dear Colleagues, Ladies and Gentlemen,

As president of the Hannover Medical School I would like to welcome you all to Hannover and at our institution. The Hannover Medical School is something very special among the 36 medical faculties in Germany, from three different points of view:

Primarily, because it is an separate university, all the others are faculties and thus part of a general university.

Then, the Hannover Medical School plays in the champion's league of the German medical faculties where research, teaching and the health care are concerned. The same is true for the trauma surgery which was set up 41 years ago (1965), at the time of the founding of the Hannover Medical School. It was led to international recognition by Prof. Tscherne as the first independent trauma surgery in Germany, a position that was held by his successor, Prof. Krettek, now administratively responsible for the Accident Research Unit of Prof. Otte.

And as a third point, which leads us right up to the subject of this international conference of ESAR, in 1973, thus 33 years ago, flanking the trauma surgery in Hannover, the unique institution of traffic accident research was set up. In that year a research project of the Federal Highway Research Institute "Bundesanstalt für Straßenwesen respectively BASt" was conducted for the first time by Hannover Medical School together with the Technical University Berlin.

In 1978 more than 25 years ago Prof. Otte took over this project and has turned it into a globally accepted institution. Accident data are continuously recorded, analyzed and transmitted since 1999 automatically to the automotive industry via a huge database of GIDAS (German In-Depth Accident Study). This way vehicles and traffic can be rendered safer.

The Accident Research Unit of the Hannover Medical School has set standards worldwide where the documentation of traffic accidents (the in-depth investigation) is concerned. As far as I know, the Hannover Team (since 1999 together with the Dresden Team) is the only globally operating research team that has permission to use vehicles equipped with flashing blue lights to reach the scene of accidents and is permitted to drive these themselves.

Some key data concerning the Accident Research Unit are remarkable for our Hannover Medical School:

Approximately 10 full-time employees und approximately 50 students are continuously employed, that means since 1973 more than 400 students and more than 50 full-time employees. Altogether research funds of more than 15 million Euro have been managed by the Hannover Medical School mostly for the BASt-Project plus other European research projects.

I am very happy that the Hannover Medical School has received such an amount of attention, acceptance and importance because of the 33 years of activity in the field of accident research. This is emphasized by this 2nd International Expert Symposium on Accident Research ESAR, with a high international participation from the fields of research as well as the automotive industries, which implement the results of the accidents research investigations for an improvement of the safety of their products. The way it appears at this point in time, accident research at the Hannover Medical School will continue to significantly contribute to the application-related, translational top-level research at the Hannover Medical School.

I wish you a fascinating and successful conference and a procreative exchange of knowledge and insights. I also hope that Prof. Otte will take a few days of relaxation after the intensive preparation of the conference and the related stress.

W. Hahn
Vehicle Safety Development, Adam Opel GmbH, Germany

Professor Kunz,

Professor Bitter-Suermann,

Professor Otte,

Ladies and Gentlemen,

I am delighted to have the opportunity to welcome you to today's conference, and all the more so because accident research is the fundamental component of my work as a vehicle safety developer. I come into contact on an almost daily basis with accident data and the associated statistics during my meetings with politicians, as a member of EEVC WG17 and in the context of my regular case studies in the GIDAS database, which frequently round off my working day.

I thus have a great deal of appreciation for all those who contribute their expertise to high-quality accident research. My words will doubtlessly reveal a highly personal view of your field of activity, the branches of science involved and your own, specific expert knowledge. I would be delighted if what I will say to you today was to enhance and enrich your dialog. Perhaps my comments will even provide new inspiration for your discussions during the two days of this conference.

Accident research is subjected to a broad spectrum of expectations. All those who make use of the results of accident research have their own requirements with respect to the information they need and the level of detail:

- Politicians need to define priorities for future law-making in the legislature.
- Researchers and engineers from various specialist fields use statistical data and in-depth studies as a basis for developing test methods, test parameters and for validating simulation tools.
- Vehicle manufacturers monitor the behavior of their products in collisions and use these results to draw up future product requirements and initiate the development of new technologies. They need information of national statistics and detailed accident analyses.

Ongoing improvements in vehicle safety over the last three decades, documented by the striking decrease in fatal and serious injuries sustained in road accidents, have only been enabled by the collective efforts of science, industry and politics. Accident research helped setting the standard for this and reported on the results.

For me, cooperation is the key word in describing the progress that has been made. Your area of work in particular, accident research, is an excellent example of interdisciplinary cooperation. You know that detailed studies and reliable data can only be obtained through close cooperation and the synthesis of expert knowledge from different sources.

In drawing conclusions, medical professionals, physicists, mathematicians and engineers focus on their specialist field and arrive at common outcomes based on the interfaces with other specialist areas. They reveal improvement potential in the first instance.

For the vehicle developer, the desired improvements are realized primarily in the form of performance objectives with directly measurable requirements. Behind these are, most importantly, the test and evaluation methods that are bundled in the development specification.

The extent to which the potential revealed by accident research can be translated into reality depends on the wealth of different factors:

- To what extent does a test procedure represent the kind of secondary injuries sustained and the causes?
- To what injury risk do the criteria apply?
- What is technically feasible?

Consequently, there is often a great deal of work required between the identification of improvement potential and predictions regarding the effectiveness of technical measures. Effectiveness assessments based on accident data are very complex.

From the very beginnings of vehicle safety work, we have been used to identifying passenger-car safety improvements principally in the area of reducing collision consequences, that is, in the area of passive vehicle safety. There were pronounced injury-related focal points for a number of dominant accident types. The effects of individual safety elements, such as seat-belts, were capable of making a major contribution to reducing secondary injuries sustained in accidents. The industry developed complex systems that have led to today's high level of safety. Accident analysis methods enable clear differentiation of the effects of these individual elements only to a limited extent. In the case of vehicle collisions, it may even be difficult to differentiate between the two causes of injury, intrusion and acceleration. When an accident occurs, the effect of safety technologies is the result of a complex overlapping of the effects of individual elements, and not the sum of their individual effects. The methods for assessing effectiveness based on accident data must take this complexity into account.

This is especially true since vehicle safety has started entering its next level, the integrated or networked safety systems, which combines collision mitigation and passive safety.

System effectiveness prediction requires sufficiently large data sets. And a great deal of in-depth data is needed over and above the large number of cases. Both together can only be obtained via data surveys over a period of years. What this means, however, is that these samples correspond to a long-term average of the vehicle population only. The latest vehicle generation, which forms the basis of research concerned with the definition of new standards, is under-represented in this.

The data describes statistical problems relating to earlier vehicle generations and compares them with the performance of the latest model generations. Usually, there are not sufficient opportunities for quantifying the difference.

What does all this mean for accident research?

On the one hand, the requirement to extend "on-the-spot" data collection and to increase the depth of the data evaluated.

- More data,
- collected systematically,
- including complete collision reconstruction and
- collision causation data
- in the shortest possible time.

As I see it, the "German In-Depth Accident Study" has gone a good way towards achieving this. Data is collected at two locations using an identical standard and is compiled in a common database.

Wouldn't it be possible to establish a comparable standard that is applicable internationally? I know how difficult worldwide standardization is, but the manner in which regional samples are intermingled, as is the case today owing to incompatible databases, collection methods etc., no longer does justice to the demands of the new vehicle generation and its integrated safety systems.

Maybe you will be able to collaborate to put the wheels in motion on this matter – across international boundaries – during these two days.

Interdisciplinary cooperation must increase to the same extent, one of the reasons being that the influence of different vehicle generations and new, networked safety systems requires technical know-how that is even more in-depth. This is a core focus of work in the industry.

As mentioned, we are experiencing a move away from the strict separation of active and passive vehicle safety towards an integrated safety system that combines elements of accident prevention and the reduction of secondary injuries. Evaluation of the effect of these systems places heavy demands on accident reconstruction. Suitable parameters for research into the cause of accidents and for describing the driver's sensory perceptions and behavior prior to the collision will be required as a component of the data collected – naturally with strict protection of personal rights.

A greater number of case studies with greater depth of data on the one hand and the necessity of data reduction as far as mathematical statistics are concerned on the other may appear contradictory to many.

An analysis of the samples from the outside and the use of assumptions to filter data cannot satisfactorily depict the effect of integrated safety systems.

Analysis in the future must be carried out on a case-by-case basis and every safety element must be taken into consideration during the chronological sequence of its effects.

Databases that enable automatic analyses of this kind will become more and more important. Computers will be able to cope with the volume of data, but data evaluation and plausibility testing will make extremely high demands of accident researchers.

The success of future accident research will, like that of networked safety systems, reside in cooperation between specialist areas in science, research and industry.

Bearing this in mind, I wish you two inspiring days of meetings, informative presentations and stimulating discussions that will help us all to forge this path.

Keynote Lectures for the 2nd International Conference on ESAR “Expert Symposium on Accident Research”

J. Hennerkes

C.E. Nash

J. Hennerkes
Secretary of the Federal Ministry of Transport, Building and Urban Affairs, Germany

Accident Research as a Basis of the German Road Safety Policy

Ladies and Gentlemen,

It is a pleasure for me to welcome you today here in Hannover to the 2nd Expert Symposium on Accident Research – ESAR.

The conference today and tomorrow has the ambitious goal to become a platform for the international exchange of knowledge resulting from so-called "In-Depth Accident Investigations".

ESAR opens the opportunity for scientists from many different countries to present their studies in this important research area.

It is a particular pleasure that this event takes place here in Hannover where the Medical University takes care for accidents investigations on the spot on behalf of the German Ministry of Transport, Building and Urban Affairs.

This is now the second time after September 2004 that this international conference is hosted by the Medical University of Hannover.

I would like to congratulate all persons involved for their ambitious work to arrange this important event.

Since mid 1999 the GIDAS project – GIDAS means "German In-Depth Accident Study" – collects accident information on the spot in the areas of Hannover and Dresden.

The main task of this important work is that real world accidents have to be documented and scientifically analysed on multidisciplinary levels immediately after the event.

Within GIDAS an extensive data pool has been collected, serving as a basis of knowledge for road safety related policy making.

One could ask if it is justified to invest these efforts in data collecting and analysing instead of investing them in e.g. new roads or other infrastructures.

Why is it necessary to carry out road safety related research with such emphasis?

On the one hand, the main task of a modern transport policy is to ensure that we maintain this high level of mobility in Europe.

Such a policy has to be based on the principle of sustainability and therefore has to balance economic, ecological and social requirements.

The mobility of the society will in future continue to be an important prerequisite for progress, prosperity, growth and employment.

Mobility means individual freedom and flexibility and therefore has to be the central aim of the European transport policy.

On the other hand, much more than 40,000 people yearly die in the European Union as a result of road accidents and more than a million get injured, some of them handicapped for the rest of their life.

Road accidents are the main cause of death in the age group below 45 and cause more deaths than heart disease or cancer in that group.

One person in three will be injured in a road traffic accident at some point in their lives.

The total cost to society in Europe has been estimated at more than € 60 billion per year, which corresponds to 2% of Europe's Gross Domestic Product.

The European Union set itself an ambitious goal, namely to halve the number of people killed between 2000 and 2010; this by way of integrated actions taking account of human and technical factors and designed to make the Trans-European road network safer.

As our neighbours from France we can testify that Germany is nearly on track to deliver its contribution to the ambitious European goals.

But the development of traffic safety differs very widely between the EU-member countries and in a few number of countries the road safety situation is even getting worse.

The German Ministry of Transport, Building and Urban Affairs set five priorities in its Programme for More Safety in Road Traffic:

- improving the traffic "climate",
- protecting weaker road users,
- reducing young drivers' accident risk,
- reducing the potential for danger presented by heavy goods vehicles and

- increasing road safety on rural roads.

Since the introduction of the Programme for More Safety in Road Traffic the number of fatalities has decreased by 6.5 percent per year – an enormous success!

Our road safety programme is involving everyone, government, local authorities, associations, safety groups, police, car manufacturers, and many others, working towards our common road safety targets.

More than hundred road safety measures were addressed with this programme, many of them have already been realised – as our road safety campaigns for more careful driving, the introduction of higher punishments for specific traffic offences and the development of a national cycling plan.

Moreover, where necessary, additional measures were taken into consideration, e.g. the planned introduction of a blood alcohol limit of zero for novice drivers. Furthermore, we are aiming at higher equipment rates of motorcycles with ABS and small trucks and light vans with seat-belt reminders.

Daytime running lights should become a standard equipment in our vehicle fleets, too.

To document the ongoing and planned activities the German accident prevention report informs periodically not only about the developments of the last years but also about each step we are going to take to continue, update and modify our road safety programme.

Research in the field of road safety is a necessary prerequisite for the implementation of potentially successful road safety measures.

It is essential to translate the knowledge based on research into action which will save human lives.

No one would disagree that the successful reduction of fatalities in the past decades has been enabled by road safety related research results, for example due to the progress made in the identification of drunk driving, urban speed reductions and improving passive car safety.

But the potentials to increase road safety due to investments in research are far from being fully exploited.

Accident analysis is therefore indeed an important topic for your conference today and tomorrow.

Based on the results of road safety related research BASt, the German Federal Highway Research Institute, which is linked to the German Ministry of Transport, Building and Urban Affairs, gives to us useful scientific advice for our national transport policy.

European research activities are nowadays as important as national research programmes. BASt has participated in EU research projects since 1994 when the 4th Framework Programme begun.

It is remarkable that 26 of the 34 European research projects in which BASt has participated deal with road safety topics, among them important ongoing projects like RIPCORD-ISEREST, IN-SAFETY, SAFESPOT, eIMPACT, TRACE, CAST or PEPPER.

Road safety related research as the basis for road traffic safety policy should address all three “pillars” of road safety:

- encourage or enforce road users to improve their behaviour,
- make vehicles safer and
- improve road infrastructure.

GIDAS comprises these three pillars of road safety in its data collection. It is recorded what the drivers and other traffic participants did during the course of the accident.

Data with regard to the involved vehicles and their passive and active safety properties are collected and information about the road infrastructure as well as the ambient conditions like weather, light and others is gathered.

Besides that GIDAS also covers rescue and medical aspects representing a fourth pillar in saving lives after an accident has happened.

Without any question, international experiences and knowledge have an influence on the national road safety policy making.

The latest German initiative regarding drink driving demonstrates this.

Based on good experiences and results reached in Austria and Spain with alcohol limits in road traffic close to zero the German Minister of Transport, Building and Urban Affairs agrees with his colleagues from the German Federal Countries that driving after the consumption of alcohol should be totally prohibited for all novice drivers and that our national rules should be adopted in this direction as soon as possible.

Beyond this activity the problem of the above-average accident risk of novice drivers has to be treated more intensively.

Research activities in this area are therefore of high importance to support the development and improvement of effective countermeasures, e.g. by

- the identification of the specific problems of new drivers in traffic and, by this, the identification of qualification needs,
- the development of appropriate forms of learning and teaching and
- the assessment of the effectiveness of educational measures as well as the development of know-how for improving them.

Medicines and drugs as well as alcohol will continue to stay in the focus of road safety related research.

DRUID, a challenging European research project about driving under the influence of drugs, alcohol and medicine, is to be launched soon.

This comprehensive integrated project – as far as I know the biggest research project ever launched in this field in Europe – deals with the scourge of drink-driving and is going to find answers to questions concerning the use of drugs or medicines which affect people's ability to drive safely.

DRUID will bring together the most experienced organisations and researchers throughout Europe, involving some 40 research institutes, universities and laboratories in 18 member states and in Norway.

Active as well as passive car safety measures play an important role in improving road safety.

The tremendous progress in vehicle safety during two decades is based primarily on the three following measures, namely seat-belts, stiff passenger compartment and airbags.

The high standard of passive vehicle safety has been achieved by establishing and updating a bundle of regulations on European and world-wide level and by assessment of vehicles within Euro NCAP. Currently it becomes evident that also active vehicle safety contributes and will contribute considerably to reducing accidents and fatalities.

Automotive engineering has achieved a significant reduction in road traffic accidents, injuries and fatalities.

Promising new technical developments like co-operative safety systems managing and using data flows between vehicles and also between infrastructure components and vehicles ensure that this will be the case in the future, too.

Since 1999 over 6,000 accidents with 11,500 vehicles have been recorded by GIDAS in the areas of Hannover and Dresden.

By means of this huge data pool a bundle of questions with regard to vehicle safety has been tackled.

The European research projects VC-COMPAT, SARAC and IMPROVER depended on GIDAS data in order to examine vehicle compatibility and the safety of Sports Utility Vehicles.

Issues with regard to whiplash, Vehicle Stability Control, pedestrian protection and brake assisting systems were analysed using in-depth accident data.

Thus data of the GIDAS project contributed and will contribute to assess road safety measures and their impact to support policy makers in taking legislative actions and vehicle manufacturers and suppliers in optimising their products.

Also in the name of the German Minister of Transport, Building and Urban Affairs, Wolfgang Tiefensee, I wish you a fruitful time during this conference, many constructive and stimulating discussions, a manifold exchange of experiences and knowledge and valuable incentives for your daily research work.

I'd like to thank you all for the work you've done over the years to make our road traffic safer.

I wish you all the best for the future and every success as you tackle the tasks that lie ahead of you.

Please never forget that those who are responsible for the policy making in Europe depend on the quality of the results of your work.

The issues you are debating here are not an end in itself. They are very much our shared responsibility.

Thank you very much for your attention.

C.E. Nash
National Crash Analysis Center
The George Washington University, USA

NASS: The Glass is Half Full

Abstract

The National Accident Sampling System (NASS) was born in the late 1970s. It was based on a substantial amount of experience and analysis of what was needed in the United States to understand the safety challenges of our highways. This work also showed how to collect high quality and useful crash data efficiently. Unfortunately, when Ronald Reagan – a President who believed in limited government – was elected, any hope of full funding for NASS was lost. The concept of 75 teams investigating about 18,000 serious crashes in detail annually was never realized. The system got up to 50 teams, then was cut to 36, and finally to 24 teams investigating fewer than a quarter of the originally anticipated number of crashes per year.

Despite this, the NASS investigations provide a rich source of data, collected according to a sophisticated statistical sampling system to facilitate detailed national estimates of road casualties on our nation's highways and their causes. In addition, changes have been made in recent years to increase the number of more serious crashes of recent model vehicles to make the results more relevant to improving vehicle safety.

A recent, detailed examination of hundreds of rollovers has provided considerable insight into rollover casualties and into what can be done to reduce them. Some of these results will be presented that show the value of the NASS system.

Our experience with NASS and the Fatal Accident Reporting System (FARS) suggests a number of improvements that could be made in the United States' crash data systems. It also provides justification for a doubling or tripling of our national expenditures on crash data collection.

Introduction

I first met Dietmar Otte in the 1970s when we were young and optimistically trying to save people from the ravages of automobile crashes. We were far less successful than I would have imagined a third of a century ago. At that time, in the U.S. we were trying to get air bags into cars, and that took far longer than we had imagined. Volkswagen had developed the automatic safety belt, and Mercedes-Benz advocated only a small head protection air bag (arguing that in Germany everyone already wore safety belts). As often happens, the result was a compromise. In both countries we were trying to find the best way to get sufficient crash data to show the best way to reduce crash casualties.

An adequate body of the right kind of crash data is the fundamental fodder for our research [Figure 1]. It is critical to diagnosing safety hazards and to making intelligent improvements in vehicle safety. Without it, we are driving in the dark with no lights.

Conducting crash investigations and reconstructing crashes can very satisfying work. Each crash is different and many present challenging puzzles: what precipitated the crash? How was an occupant injured? Who or what performed well or poorly? What could have prevented the crash or ameliorated the injuries? But we must not forget that our ultimate aim in this grizzly business is to learn how we can put ourselves out of business by making our automobile transportation even safer than rail or air transport.

Of course, the problem is difficult because automotive transportation is the original amateur hour: at least in the U.S., there are no professional requirements to be an automotive engineer. Anyone can be an auto mechanic. And then there are the drivers.

Vehicle Crashes:
a Public Health Challenge

- Crash data is critical to diagnosing why vehicles crash and how people are being hurt.
- Sampling is necessary to assess the epidemiology of crash injury.
- The cost of collecting high quality crash data is trivial compared with the benefit that can come from the insights it can provide.

Figure 1

Some History of U.S. Crash Data Systems

In the United States, one of the earliest programs to conduct serious investigations of crashes was initiated in the 1950s by the brilliant safety pioneer, Hugh Dehaven, at Cornell Aeronautical Laboratories' Automotive Crash Injury Research program [Figure 2]. The data collected in his program led to a better understanding of how people were hurt in crashes. The Public Health Service's Multidisciplinary Accident Investigation program was modeled on the Cornell program.

NHTSA made various attempts to understand specific aspects of, or types of crashes including programs on pedestrian accidents, restraint performance, crash avoidance, and fatal crashes. In the late 1970s, the agency settled on two basic systems: the Fatal Accident Reporting System (FARS) – basic data on a census of fatal crashes – and the National Accident Sampling System (NASS) which provides detailed data on a statistical sample of all crashes occurring across the country [Figure 3]. FARS conducts no independent investigations, relying essentially on police reported data.

Early Crash Investigation Programs

- Automotive Crash Injury Research of Cornell Aeronautical Laboratories (Hugh DeHaven)
- Multidisciplinary Accident Investigation Program (MDAI – Public Health Service)
- Tri-Level Studies: National Crash Causation Study and National Crash Severity Study
- Restraint System Evaluation Project, Pedestrian Injury Causation Studies, etc.

Figure 2

Current NHTSA Programs

- Fatal Accident Reporting System (FARS)
- National Accident Sampling System (NASS)
  - – Crashworthiness Data System (CDS) – detailed investigations of a sample of crashes
  - – General Estimates System (GES) – police data only on a larger sample of crashes
- Special Investigations
- State Data Systems and Programs
- Crash Injury Research and Engineering Network

Figure 3

National Accident Sampling System

NASS was a design using a sophisticated statistical sampling model that ensured that the data could be used to make national estimates of what was happening on our nation's roads [Figure 4]. It provided for a crash investigation team of two to four investigators in each Primary Sampling Unit (PSU). There was to be a PSU representing each of the 75 geographic and demographic levels defined by the Census Bureau. NASS teams sample crash reports at a set of police agencies, and an algorithm is used to decide which to investigate. Each investigator would conduct detailed investigations of two crashes per week: documenting the scene and vehicle with measurements and photographs, interviewing the people involved in the crash, and reviewing and coding data from medical records.

Unfortunately, when Ronald Reagan was elected, any hope of full funding for NASS was lost. The concept of 75 teams investigating more than 18,000 serious crashes in detail annually was never realized. The system got up to 50 teams, then was cut to 36, and now only 24 teams investigate a

National Accident Sampling System

Original NASS Design

- 75 teams – a Primary Sampling Unit in each Census Bureau geographic/demographic stratum
- 2 to 4 investigators in each PSU each investigating 2 crashes per week
- Crashes selected by a statistical sampling algorithm to provide a representative sample
- Over sampling of later models, more severe crashes.
- Detailed characterization, photos of vehicle and scene, interviews with people, review of medical records, reconstruction of crash, coding of all data.

Figure 4

Current NASS

- Only 24 teams investigating fewer than 5,000 crashes per year
- Concentrates on light vehicles, generally ignores pedestrians, heavy trucks, etc.
- Improved selection of cases
- Improved training, protocols, data elements, . . .
- New special studies being added
- All data is available on the web:

http://www-nrd.nhtsa.dot.gov/departments/nrd-30/ncsa/

Figure 5

quarter of the anticipated number of crashes per year [Figure 5].

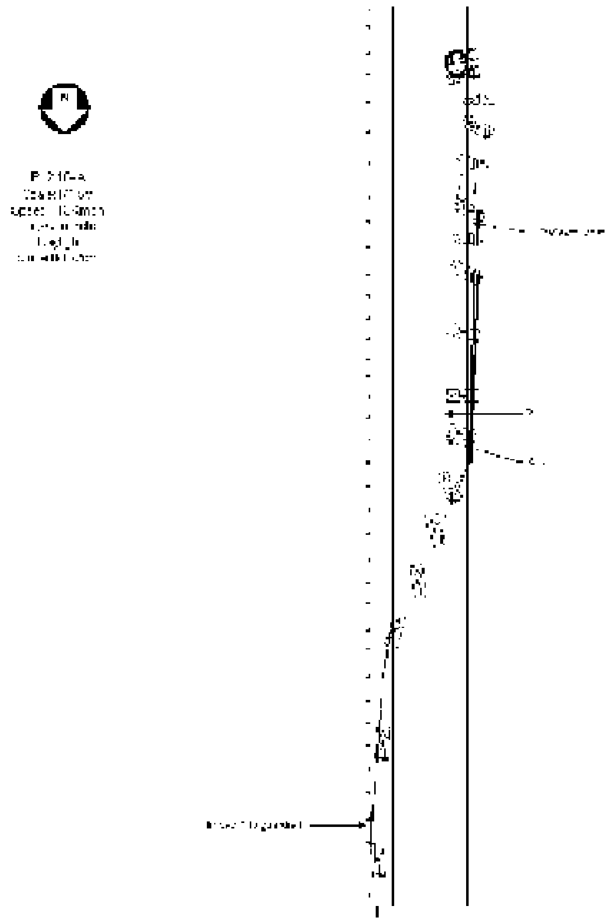
Despite this, the NASS investigations provide a rich source of data, collected according to a sophisticated statistical sampling system to facilitate detailed national estimates of road casualties on our nation's highways and their causes. Changes have been made in recent years to increase the number of more serious crashes of recent model vehicles to make the results more relevant to improving vehicle safety and to improve the relevance, quality and completeness of NASS data [Figure 6].

All of the NASS and FARS data have been public from the beginning except for information that would permit specific identification of the individuals involved so as to protect their privacy. For several years, all of the NASS data have been more readily available on the NASS web site [Figure 7].

Case Number: 2001-12-164

Summary:

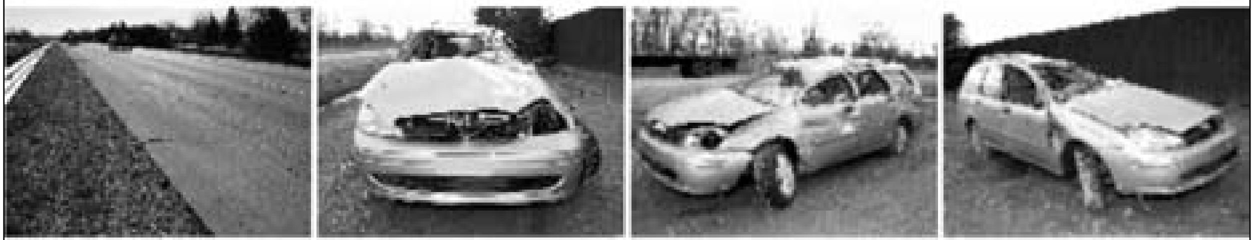
Vehicle 1 was travelling southbound on a 2 lane, dry concrete expressway with a divided traffic median with positive barrier. Vehicle 1 was traveling in the fast lane and gradually departed the left shoulder striking the median guandrail with its left side. The path of the vehicle then continued forward reentering the roadway crossing all traffic lanes. The driver overcorrected by steering left to avoid departing the roadway into a ditch off the right roadside. In doing this, the vehicle yawed counterclockwise and with the back wheels of the vehicle on the grassy roadside, and the front wheels still traveling on the paved shoulder. The right wheels gouged into the grass tripping the vehicle causing a right rollover sequence (six quarter turns) coming to rest on it's top. During the rollover, the driver was partially ejected from the left front glazing which caused fatal injuries to the head and neck. The driver was partially entrapped underneath the vehicle at final rest. All occupants had been restrained. All occupants were transported to a trauma facility for treatment of injuries. The vehicle was towed from the soene due to damage. During the crash sequence, the left side airbag deployed, no other airbags deployed, no pretensioners fired.



Vehicle	Body type	Make	Model	Year	Occ. #	Age	Occupant's sex	Maximum known occupant ais
1	STATION WAGON	Ford	Foccus	2001	1	46	MALE	2=Moderate
1	STATION WAGON	Ford	Foccus	2001	2	46	FEMALE-NOT PREG	1=Minor
1	STATION WAGON	Ford	Foccus	2001	3	15	FEMALE-NOT PREG	1=Minor
1	STATION WAGON	Ford	Foccus	2001	4	15	FEMALE-NOT PREG	0=None
1	STATION WAGON	Ford	Foccus	2001	5	15	FEMALE-NOT PREG	1=Minor

Figure 6 A NASS rollover case – crash description and scene diagramm

Occupant: 2001-12-164-1-1



Rollover Characteristics

Number of Events	3
Rollover Initiation Type	TRIP-OVER
Location of Rollover Initiation	ROADSIDE/MEDIAN
Rollover Initiation Object Contacted	GROUND
Location on Vehicle where Principal Tripping Force was Applied	WHEELS/TIRES
Direction of Initial Roll	ROLL RIGHT

Crash Severity

Nr. Quarter Turns	6 QUARTER TURNS
Impact Speed	999
Total, Longitudal, and Lateral ΔV	999 999 999
Est. ΔV with sequence number	SEVERE 2
CDC	0 T D D O 5
Damage (C1-C6)	0 0 0 0 0 0
Crush (L and D)	0 0
Object Contacted 1	ROLLOVER-OVERTURN
Object Contacted 2	Other BARRIER

Pre-Crash Environment

Traffic Flow	DIVIDED/W/BARRIER
Number of Travel Lanes	TWO
Roadway Alignment	STRAIGHT
Roadway Profile	LEVEL
Roadway Surface Type	CONCRETE
Roadway Surface Condition	DRY
Light Conditions	DAYLIGHT
Atmospheric Conditions	No ADVERSE COND
Relation to Intersection	NONINTER/NONJUNC
Traffic Control Device	
Police Reported Alcohol Presence	No ALCOHOL
Alcohol Test (< 95 indicates BAC 0.xx)	0

Vehicle Factors

Make-Model	Ford Focus
Year	2001
Class	
Body Type	STATION WAGON
Weight	119

NASS Weighting Factor

Weighting factor	33.915

Pre-Crash Driver Data

Accident Type	6
Pre-event Movement	GOING STRAIGHT
Critical Pre-crash Event	OFF EDGE-LEFT
Attempted Avoidance Maneuver	No AVOIDANCE
Pre-impact Stability	TRACKING
Pre-impact Location	DEPARTED ROADWAY

DRIVER Factors

Age	46	Height	180	Weight	82
Gender			MALE		
Ejection			PARTIAL EJECTION		
Ejection Area			Left FRONT		
Entrapment			ENTRAPPED		

Restraint Factors

Restraint	Lap and shoulder
AOPS	YES-RES DET
Airbag Deployment	NONDEPLOYED
Airbag Deployment - 1st Seat	NONDEPLOYED
Airbag Deployment - Oth Seat	BAG DEPLOYED

Injuries

Occupant	2001-12-164-1-1
MAIS	2=Moderate
Seat Position	Front left side

AIS Level	Injury Description	Contacts
2=Moderate	751900	Left A pillar
1=Minor	Scalp avulsion, NFS	Roof left rail

Figure 7: Details on the vehicle & occupant injuries

Use of NASS Data to Study Rollovers

Now, I would like to show you what can come from a major study of the crash data that we have. I have been seriously interested in rollover crashes for nearly a decade. Fully one third of all serious to fatal casualties in light motor vehicles in the U.S. are in rollovers. However, until I personally looked at every rollover of a vehicle less than ten years old in which there was an AIS 3 injury, I did not fully understand what was happening in these crashes [Figure 8].

It became obvious as I looked at these crashes that the traditional ways of classifying rollovers – the number of quarter turns or the manner in which the rollover was initiated – was of little practical use. Rather, I found that rollovers fell fairly neatly into five classes [Figure 9]:

- Rollovers where an unbelted occupant is completely ejected.
- Rollovers where a belted occupant receives a head or neck injury from roof crush.
- All other pure rollovers (i.e. without a significant collision).
- Rollovers that follow a major collision that is the most harmful event.
- Rollovers in which there is a major collision or change in elevation during the rollover where that is the most harmful event.

I used a sophisticated version of the Harm concept developed initially by the late Dr. Sakis Malliaris at NHTSA, to assess the consequences of the rollovers I found in NASS. That methodology computes the product of the economic cost of an injury and the frequency of occurrence of that injury to get an economic measure of its consequence [Figure 10].

Since each crash in NASS has an estimate of the number of similar crashes in the U.S., I could make a reasonable estimate of the economic consequence of each of the rollover crashes I found in NASS that involved a serious to fatal injury.

A Study of NASS Rollover Cases

- Studied all rollovers of vehicles 10 years old or less with AIS 3+ injuries in years 2002 -2004
- Determined type of rollover and cause of injury
- Calculated economic consequence of injury (HARM = Cost x Frequency of Occurrence)
- Estimated the effectiveness in each crash of:
  - a strong roof
  - laminated side windows with edge containment
  - a strong safety belt use reminder
- Calculated value of countermeasures

Figure 8

Classes of Rollovers

1. An unbelted occupant is completely ejected.
2. A belted occupant receives a head or neck injury as a consequence of roof crush.
3. All other pure rollovers (i.e. without a significant collision)
4. Rollovers that follow a major collision where the collision is the most harmful event.
5. Rollovers in which there is a major collision or change in elevation during the rollover where that is the most harmful event.

Figure 9

AIS	Body Part	Cost	AIS	Body Part	Cost
3	SCI	$ 1,506,961	5	SCI	$10,210,387
	Brain	$ 1,306,647		Brain	$ 6,826,032
	Lower Extremity	$ 530,725		Lower Extremity	$ 2,056,783
	Upper Extremity	$ 235,160		Upper Extremity	N.A.
	Trunk, Abdomen	$ 266,856		Trunk, Abdomen	$ 860,798
	Face, Head, Neck	$ 325,650		Face, Head, Neck	$ 1,805,288
4	SCI	$ 7,296,260	6	All	$ 3,623,787
	Brain	$ 2,939,047			
	Lower Extremity	$ 1,161,530			
	Upper Extremity	N.A.			
	Trunk, Abdomen	$ 480,459			
	Face, Head, Neck	$ 869,853			

Figure 10: Cost of AIS 3+ Injuries by Body Part and Severity of Injury from NHTSA's "Economic Inpact of Motor Vehicle Crashes"

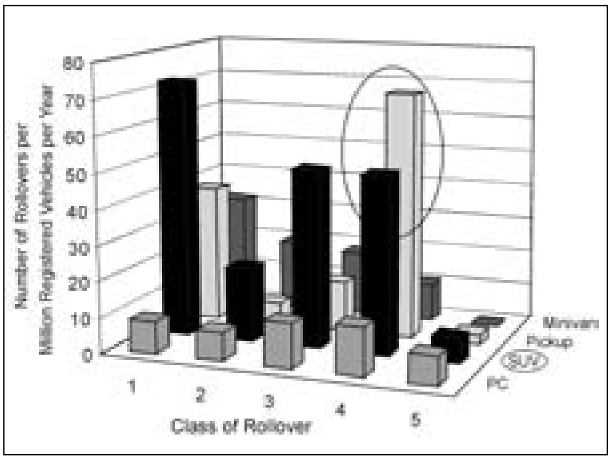


Figure 11 Rollovers per Million Registered Vehicles per Year

What is most striking about what I found is the substantial overrepresentation of SUVs where an unbelted occupant is ejected [Figure 11]. I was also somewhat surprised by the fact that roughly one-third of all rollovers have a collision before or during the rollover as the most harmful event. The differences in these two figures are that the first shows only the estimated counts of rollover injuries while the second shows the harm, in economic terms [Figure 12].

Looked at this way, we can immediately see how to substantially reduce rollover casualties. I picked three basic countermeasures: a strong roof, belt use (i.e. effective belt use reminders), and side windows that do not break out as a consequence of roof contacts with the ground. I then made an estimate of the effect of these countermeasures on the casualties that occurred in the rollover: how much the harm would be reduced by the countermeasure [Figure 13].

Using this technique, I made an educated prediction of the effectiveness of these simple countermeasures. Now, I realize that the sexy technologies for rollovers are electronic stability systems and rollover-triggered window curtain air bags. Yet even in full production, each of these would add $ 250 or € 200 to the cost of a new car. By comparison, the combination of a strong roof, an effective safety belt use reminder, and laminated side glazing would add a total of less than $ 200 or € 160 to the price of a typical car or light truck. Yet these three together would be substantially more effective overall in reducing casualties than the fancy new technologies [Figure 14].

I also learned by looking in detail at the NASS rollovers that you would get a substantial part of the total benefit by applying these countermeasures only to SUVs. It is interesting that either an effective safety belt use reminder or laminated side glazing could deal with the problem of complete ejections in rollovers. However, laminated side glazing will not contain occupants if the roof distorts substantially during a rollover. Thus, for this to be a successful countermeasure requires a strong roof as well [Figure 15].

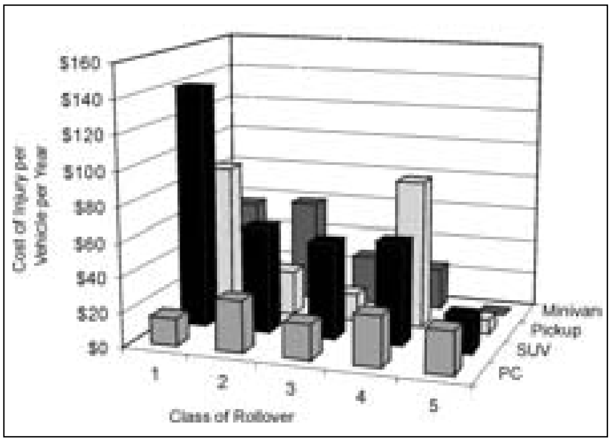


Figure 12: Cost of Injury in Rollovers per Vehicle per Year

Figure 13

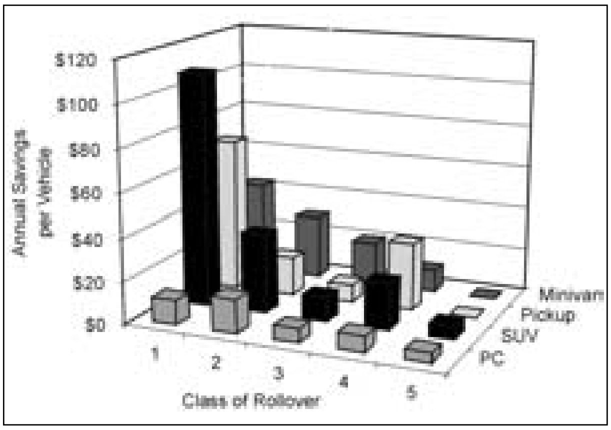


Figure 14: Savings from Common, Low Cost Countermeasures per Vehicle per Year

Class of Rollover	Passenger Car	SUV	Pickup	Minivan
Unbelted Occupant Fully Ejected	$ 2,177	$3,658	$3,359	$ 1,004
Belted Occupant w/Head or Spinal Column Injury	$ 4,061	$1,600	$1,016	$ 1,062
Other Primary Rollovers	$ 2,768	$1,461	$ 612	$ 511
Collision Before Rollover	$ 3,925	$1,546	$3,340	$ 439
Collision During Rollover	$ 3,399	$ 561	$ 311	$ 0
Total	$16,330	$8,826	$8,638	$3,016
Number of Vehicles in Use (In millions)	127	17	37	18
Annual Cost per Vehicle in Use	$130	$520	$230	$165

Figure 15 Annual economic consequences of rollovers per vehicle by type of vehicle and class of rollover (in millions). The sum for all light vehicles is $ 36.8 billion per year

It is clear from reviewing the pictures in the NASS files that most cars on the road in the U.S. – and that includes some German and Swedish cars – do not have adequately strong roofs. It is also clear that a typical vehicle's pitch angle during a rollover is at least 10º as shown by damage to the front fenders of vehicles, and that the windshield always breaks when there is damage to the front of the roof. These types of observations show the importance of reviewing cases in detail to get ideas about both countermeasures and about designing useful performance tests for safety performance. To rely simply on the electronic files of systems like FARS and NASS can not only deprive one of the richness contained in the complete file; it may mislead an analyst.

No Cause for Optimism

When thinking about data, we must remind ourselves that highway crashes are fundamentally a public health challenge: little different from cancer, bird flu and AIDS in either their impact on society or in how we should approach them. The lack of sufficient crash data in the U.S. meant that we were unable to see problems with the first generation air bags, and with automatic belts, until these systems had killed a significant number of people. We also did not see the problem with Firestone tires on Ford Explorers until they had killed hundreds of people.

Although I don't want to cast a pall over this meeting, I am increasingly feeling that despite our air bags, electronic controls and advanced materials, we have progressed only modestly in the 40 years since Ralph Nader published "Unsafe at Any Speed" [Figure 16].

Why is the Glass Only Half Full?

- A lack of complete commitment to safety by the auto industry (it will not even lobby for a comprehensive U.S. crash data program).
- The public still thinks "the nut behind the wheel" causes crashes, and that "I'm a good driver: it can't happen to me."
- Belt use among people who are most likely to be in a serous crash is depressingly low.
- NHTSA has lost its drive and support.

Figure 16

The U.S. auto industry still lacks a comprehensive commitment to safety that involves strong support of research and the application of all known, practicable safety advances in a timely manner to its products. The industry has not even supported a strong, well funded crash data system in the U.S. that would help it make cost-effective safety improvements in its products. There is little public concern over the massive loss of life on our roads. There is a pervasive public attitude that the problem is still mostly "the nut behind the wheel," and that "it can't happen to me". Safety belt use among those most likely to be in a serious crash remains depressingly low.

Our National Highway Traffic Safety Administration has become a toothless shadow of its former self: drastically under-funded, politically hamstrung, and focused on programs and initiatives that have only modest payoff but are inoffensive to industry. Although NHTSA has collected a substantial body of crash data, it does little to diagnose current auto safety challenges or to evaluate designs and technologies that would reduce casualties.

A Trauma-Based Crash Data System

In attempts to improve the understanding of crashes in the U.S., ten years ago NHTSA initiated the Crash Injury Research and Engineering Network (CIREN) based at eight trauma centers around the country. Some of the centers are sponsored by auto makers. CIREN produces a small number of detailed investigations of crashes that have very severe outcomes. CIREN cases include particular detail on the medical aspects of crash injuries and treatment. The investigations are triggered by the admission of an individual to the trauma center for severe crash injuries.

While the CIREN cases are interesting and useful, they lack a basis in statistical sampling, so that it is difficult to determine the importance or breadth of problems identified in them. NHTSA has several other crash data programs, mostly in cooperation with the states, and I leave it to you to learn of them from the NHTSA web site.

A Future U.S. Crash Data System

As a result of my work, I have given further thought to how we could improve the crash data systems in the U.S. [Figure 17]. We spend roughly $ 25 million

U.S. Data Collection in the Future?

- Continue the existing FARS program
- Expand the NASS program to its originally designed size of 75 teams investigating a sample of more than 18,000 cases per year.
- Conduct full NASS investigations of a sample 5,000 fatal crashes
- Crash Causation: install a GPS, video camera (~1 frame/second), sensors (brake pressure, steering angle, and throttle position), and data recorders in a fleet of 1000+ vehicles to monitor emergency conditions (whether there is a crash or not)
- Increase funding to at least $75 million per year

Figure 17

on Federal crash investigation and data programs. This is less than $ 1 for every $ 10,000 in economic loss from crashes. While I suppose we should be thankful that we have at least that amount of information, it is a travesty that a rich, advanced country like the U.S. collects so little data on this critical problem.

I think that a reasonable crash investigation program would have the following:

- Continuation of the existing FARS program.
- Expansion of the NASS program to its originally designed size of 75 teams investigating a sample of more than 18,000 cases per year, and closing of the General Estimate System.
- A new program that will sample roughly 5,000 fatal crashes in the U.S. with NASS personnel conducting detailed investigations of them.
- A new project on crash causation where Global Positioning Systems, video cameras (taking only about one frame/second), sensors (brake pressure, steering angle, and throttle position), and data recorders are put in a fleet of at least 1,000 vehicles to monitor emergency conditions (whether there is a crash or not). This project would give critical, real time information on the conditions that immediately precede an actual crash or a near crash.

We would need at least $ 75 million per year for what I would consider a reasonable crash investigation program in the U.S. NHTSA also needs to have a much more comprehensive program to analyze the data it already has to identify problems, set priorities, and justify a more dynamic vehicle safety program.

It might be useful to develop cooperative international programs in crash investigation. Such programs have not occurred in the past because of major institutional impediments, not to mention budgetary, language and philosophical constraints. Further problems are the significant differences in the vehicles and fleets in the major areas of the world as well as in their differing traffic conditions. Even without greater formal cooperation, we can clearly learn much from each others programs and experiences.

Frankly, I think that the area that could provide the highest payoff in international cooperation, it is the New Car Assessment Program. Although this concept was first developed in the United States in the late 1970s, Europe and Australia have taken it considerably further than we have. NCAP can have major payoff in improving vehicle safety without resorting to more regulation.

That is the beginning of my dream for safe motor vehicle transportation.

Session:
Methodologies of In-Depth Investigations

I. Salo, K. Parkkari, P. Sulander, E. Keskinen

C.Y. Kong, J.K. Yang, L. Li, W.Q. Li, Z. Zhao, D. Otte

A. Tenzer, W. Hongyan

W. Klanner, T. Unger

J. Lenard, A. Morris, E. Tomasch, J. Nehmzow, D. Otte, L. Cant, M. Haddak, G. Vallet, H. Ebbinger, J. Barnes, Y. de Vries, B. van Kampen, J. Paez

H. Hautzinger

M. Pfeiffer, J. Schmidt

J. Gail, U. Ellmers

M. Jänsch, D. Otte, C. Krettek

Y.W.R. de Vries, N.A. Jongerius

I. Salo, K. Parkkari, P. Sulander
Finnish Motor Insurers' Centre, Traffic Safety Committee of Insurance Companies, Finland

E. Keskinen
University of Turku, Department of Psychology, Finland

In-depth on-the-Spot Road Accident Investigation in Finland

Abstract

In Finland all fatal motor vehicle accidents are studied in-depth on-the-spot by multidisciplinary (police, road and vehicle engineers, physician and behavioural scientist) road accident investigation teams (legislation 2001, work started 1968), which operate in every province. The purpose of the teams is to uncover risk factors that turned an ordinary driving situation into a serious accident and give safety recommendations for improving road safety. The investigation teams do not take a stand on guilt or insurance compensation. When analysing accidents the teams use the concepts of key event, immediate, background and injury risk factors. Compiled investigation folders of each case contain investigation forms from each member, pre-investigation protocol, photographs, sketches etc. About 500 items of information are collected from each accident party. The collected information is also coded into a computer database. Both the database and the investigation folders are widely utilized by researchers and authorities conducting safety work.

Introduction

The general goal of Finnish road accident investigation is to prevent accidents from happening again and reduce serious consequences by learning from accidents. The investigation of road and cross-country traffic accidents produces information and safety recommendations, which are used to improve road safety. In Finland, the work is based on investigations performed by the multidisciplinary investigation teams. The teams are independent and impartial while carrying out their investigations and do not take a stand on guilt or insurance compensation. The teams use an in-depth on-the-spot case-study investigation method called VALT Method 2003 [1], which forms the basis of this paper. The focus of the investigation is on pre-crash circumstances, but also the crash and post-crash stages are investigated. The investigation teams investigate all fatal road traffic accidents in Finland.

In aviation, an in-depth on-the-spot method for investigating accidents has been used from the beginning of aviation's history. In many countries, these kinds of methods are also in use in road traffic as a part of safety work. Usually the investigations have concentrated on limited areas or certain kinds of accidents for a limited period. In Denmark, multidisciplinary in-depth analyses of road traffic accidents were used to study head-on collisions, left-turn accidents, truck accidents and single vehicle accidents [2, 3]. In Sweden, accident investigation teams studied accidents on a trial basis in the 1970s focusing on the pre-crash phase [4] and investigations were also carried out by the Swedish National Road Administration in 1991-1994 [5]. The Swedish Road Administration carries out investigations also currently [6]. In the FICA-project (Factors Influencing the Causation of Incidences and Accidents) in Sweden, an investigation methodology suitable for investigating active safety systems was developed (DREAM, Driving Reliability and Error Analysis Method) [7]. In the UK, an on-the-spot accident data collection study was carried out to gain a better understanding of the human, vehicle and highway factors on the causes of accidents and injury outcomes [8]. The German In-depth Accident Study (GIDAS) provides in-depth accident and injury data of traffic accidents [9]. In the United States, an in-depth on-scene methodology was used e.g. in the Large Truck Crash Causation Study [10]. In the U.S., extensive data on fatal motor vehicle accidents is collected in the FARS database (The Fatality Analysis Reporting System) [11]. Within the SafetyNet project, are European Commission is developing a methodology for capturing accident causation data using in-depth accident investigations [12].

Background to Finnish road accident investigation

Road accident investigation teams were launched in Finland in 1968 when the Finnish Motor Insurers Centre started them in collaboration with road safety authorities to gain information on accidents.

Around 1970s, there were about 1000 fatalities in road traffic per year, which was more than ever before and ever after. Based on the favourable experiences gained, more teams were established and they covered the whole country by 1976. Nowadays accident investigation is financed with a road safety charge collected in connection with motor liability insurance premiums. The size of the charge is confirmed annually by a decree issued by the Ministry of Social Affairs and Health.

Since 2001, the work of the investigation teams has been based on law. The Act on the Investigation of Road and Cross-country Traffic Accidents (No. 24/2001) and the Council of State decree (No. 740/2001) came into force 1st of October 2001 [13]. Finland is the only country to have such legislation. According to the act, the Road Accident Investigation Delegation appoints the road accident investigation teams, which carry out the investigation of traffic accidents. The Delegation comprises representatives from at least the following authorities: Ministries of Transport and Communications, Interior, Social Affairs and Health, Justice, Education; the Finnish Road Administration; the Vehicle Administration and the Finnish Motor Insurers' Centre. The Finnish Motor Insurers' Centre manages the maintenance of investigations.

Accidents to be investigated

The teams investigate accidents that have been defined in advance annually according to the action plan confirmed by the Ministry of Transport and Communications. The teams in Finland investigate all fatal road traffic accidents (about 350 a year) which include pedestrian and cyclist accidents. In addition, special projects are also carried out, e.g. heavy vehicle accidents, snowmobile accidents and powered two-wheeler accidents leading to injuries. In total, the teams investigate approximately 400 accidents a year.

Investigation Teams and Investigations in Practice

The investigation work is based on a detailed investigation method (VALT Method 2003 [1]), which describes how the investigation is to be carried out. Both the information collection and the analysis of the origin of accident and consequences are described in the method. The method contains investigation forms of the team members and other instructions etc. The investigation method has been designed primarily for investigating accidents that have led to fatalities. It can also be used as a basis for investigation of other accidents; then additional forms and instructions are often employed. The method has been revised several times to take into account the demands of the present traffic safety work. The latest revision came into force in 2003.

Investigation teams

The investigation method has been designed for multidisciplinary expert teams. At the moment, there are 20 teams throughout the country with about 270 members. Basic members of the teams are a police officer (usually the chairperson of the team), a vehicle specialist, a road safety specialist, a physician and a behavioural scientist (usually a psychologist). Other experts may also be included in the investigation when needed (e.g. a railway or tram specialist, a bus body specialist, and special advisors who represent specialist areas in vehicle safety, commercial traffic, or traffic medicine). The team members work on a voluntary basis and get compensation for their work. While carrying out their investigation work, the teams are independent bodies so that the neutrality and impartiality of the investigation are ensured. The members, when performing the investigations, are governed by the provisions applied to civil servants' liability under criminal law and they are bound by duty of secrecy.

Investigation team called out when an accident has happened

The emergency centre or the local police officer will notify the investigation team about the accident. Usually the police member of the team acts as a contact person whom the alarm is notified and who then calls out the other members.

The method works effectively when the team arrives at the scene soon after the accident. Any delay in investigation reduces the quality of the information available. Usually the following members visit the accident scene on the spot: police member, road specialist and vehicle specialist. Investigation may also be carried out later if the call is delayed for some reason, for example a later fatality after an accident. The work of the teams is not tied to certain working hours, so also night time and weekend accidents are investigated.

Operation at the scene of the accident and team members' tasks

The investigation team begins investigation at the accident scene. The quick arrival at the scene ensures that, for example, the braking and skidding marks can be found clearly and that the road and weather conditions can be documented and photographed reliably. The investigation at the scene of the accident is conducted in cooperation with the police conducting preliminary investigation as part of the same case, to the extent deemed appropriate for the investigation of the road accident. The factual information may be clarified together with the police and rescue staff, e.g. point of impact, directions of travel of those involved, the marks found and the general characteristics of the incident. The police also help to secure the investigation conditions at the accident scene. However, further accident analysis and interviews done by the investigation team are carried out apart from police preliminary investigation and apart from any other investigation that may be carried out under different authorities. The police member of the investigation team does not take part in the preliminary investigation performed by the police authorities.

The police member of the team usually acts as the chairperson, leads the work, interviews participants, organises photography and sketch drawing, orders pre-investigation protocols, autopsy statements and other necessary documents from the local police and other authorities. He/she collects the information on previous accidents and traffic offences of the parties involved.

The vehicle specialist member examines and photographs the vehicles (technical condition and damage) and the use of safety equipment. The vehicle specialist collects information e.g. from the following areas: general information about the party (make, model, last inspection, engine etc.); external inspection (headlights, doors, suspension of wheels etc.); interior inspection (windscreen, control equipment, pedals, mirrors, seats, safety equipment etc.); tyres (make, model, pressure, studs etc.); crash and damage to the vehicle; information relating to the impact(s). The vehicle specialist has also additional investigation forms concerning bicycles, mopeds, motorcycles, buses and snowmobiles.

The road specialist member examines and photographs the road and weather conditions, traffic environment etc. The road specialist prepares a sketch of the scene based on measurements regarding the onset of braking, sliding and impact marks, vehicles involved, rest positions and locations of loose objects and debris. The investigation forms of the road specialist cover the following areas, for example: scene of the accident and characteristics of the road (functional class of the road/roads, road layout, radius of the curve, number of lanes, separation of the lanes, surface etc.); visibility (was the visibility sufficient for the speed used or the speed limit, factors that restricted the visibility etc.); guidance of traffic (traffic signs, speed limit etc.); condition of roads (state of roads, friction etc.); maintenance (winter maintenance class; damage on the road etc.); weather and brightness; traffic volume; pedestrian and cyclist accident information.

Physician member mainly examines documents. He/she clarifies the fatal and other injuries and looks for the origin of injuries. The physician also obtains historical information about the health of the accident parties involved and evaluates the effect of these on the origin of the accident. Both the AIS-98 (Abbreviated Injury Scale) and the ISS (Injury Severity Score) are used in coding the injuries. ICD-10 (International Statistical Classification of Diseases and Related Health Problems) is used in determining the cause of death as well as effects contributing to death. About one third of the physicians of the teams are medicolegal experts.

The behavioural scientist member of the team, according to the division of labour the team has agreed on, interviews participants and gathers information about the health of the road users. Based on information collected also by other team members, he/she evaluates the behaviour of the participants in relation to the traffic environment, the vehicle and other road users and the motivational factors relating to the accident. The behavioural scientist functions as an expert in research questions within the team.

Interviews

Conducting the interviews as soon as possible after the accident, although preliminary and partial, is important from the point of view of the reliability of the information. As most of the accidents investigated have led to fatalities, the drivers or occupants cannot be interviewed in many cases. Then the possible information on the background of the parties involved are gathered from relatives, friends etc. Information on the actual accident is collected from eye-witnesses and other parties. Taking part in the interviews is voluntary. In practice, the parties or relatives rarely say no to the interviews. The interviews, performed usually by the police or the behavioural scientist member, cover e.g. the following areas:

- General information on the parties involved (marital status, profession, current work assignment etc.).
- Information related to the location and situation of the accident (actions before the accident, focus of attention, speed, when the danger was noticed, how the collision partner reacted etc.).
- Use of safety devices and lights (also investigated by other means).
- Driving event and vehicle (the purpose and length of the trip, total driving time, breaks during the trip, haste, passengers and their influence, familiarity of the accident location, keeper of the vehicle, basis for the use of the vehicle, route decision etc.).
- Driving control and readiness to act (sleep, use of spectacles or sunglasses, permanent illness, medication, alcohol and drug use at the time of the accident [also obtained from breath test or blood test], time of last meal, problems in life, emotional stage etc.).
- Factors which explain the driving conditions or life style (educational background, alcohol and drug use etc.).
- Driving skill, training background and attitude to traffic (grade of driving license and its validity, total and current annual mileage, total mileage driving the accident vehicle, quality of driving experience, avoidance of certain circumstances, previous traffic accidents and offences over a five year period [also obtained from police registers], activities and hobbies related to driving and traffic, own and others' description of the party in relation to traffic etc.).

Investigation forms

Each team member collects detailed information (as described above) using standardised investigation forms. The investigation forms are tools of systematic data acquisition; the reliability of the investigation depends totally on the quality of the forms, usually ticking the appropriate alternative fills in the form. Totally, there are approximately 500 items to be collected from each party. Part of the collected items come from scene investigation, part from different registers and part from interviews. Additional forms for rare accidents and special projects are also available. In addition, any other relevant information which is not collected on the forms but relates to the origin of the accident and consequences is written down and taken into consideration in the investigation. All sections in the forms are filled in regardless of whether the item in question has an effect on the origin of the accident or its consequences. This secures the baseline comparison data for further research.

The members of the investigation team have the right to obtain information from different registers. Information can be obtained from the police registers (previous offences and accidents) and the road traffic registers (Traffic Data System), which is maintained by the Finnish Vehicle Administration. In addition to these, the team has access to any information on the health of the persons involved that may be of importance for identifying the causes of the accident (also from the private health care) and to any other information needed for the conduct of investigations.

The investigation forms can also be filled electronically, but in practice, the on-the-spot method requires paper and pencil. A system for electronic transmission of data contained on the forms is under construction. The information collected on the investigation forms is coded into a database at the Finnish Motor Insurers' Centre after the investigation is completed.

Technical reconstruction

The calculation of the driving and impact speeds of those involved creates a framework for the definition of the factors which have affected the origin of the accident and its consequences. It is appropriate to calculate or roughly estimate the speeds of those involved at intervals of one second. The accident is reconstructed on the basis of information recorded at the accident scene including the rest positions of the vehicles and persons involved in the accident as well as marks on the road surface and damage to the vehicles. At its simplest, a reconstruction is a sketch in which the speeds and distances from the crash location of the parties involved at their different stages (in seconds) in the accident are illustrated. When appropriate, more detailed reconstructions using dedicated simulation programs can be made.

Cooperation between members and quality of investigations

An important stage in the evaluation of the adequacy, significance and reliability of information is the combining of the pieces of information with each other and with the entire accident event. The team members cooperate with each other during the investigation by changing information and making conclusions. For example, the use of safety equipment is considered together with the vehicle specialist, the physician and the police member. During years of cooperation, the teams have developed their own working patterns and ways of delivering information to other members of the same team. Many of the members have participated in the work for many years, even decades.

In general, all pieces of information must be consistent with each other. If this is not the case, other alternatives to the sequence of events are considered and the reliability of the individual pieces of information is evaluated again. Based on re-evaluation the team tries to find a mutual understanding of the factors related to the accident. If however a team is not able to explain some factors, which are related to the event or if the event may be a consequence of several alternative key events or immediate risk factors (the concepts are explained later in the text) then the reliability of the investigation will increase if the team reports that it had been unable to explain a certain issue. Therefore, it is better to state that there are alternative possibilities for events than to choose an alternative for which there is no reliable basis. In practice, these kinds of cases are rare.

The revision of the investigation method together with continuous training of the investigation teams adds to the reliability of the investigation. It is also important to define unambiguously the concepts used and make sure that the instruments used are appropriate. One way to develop the methodology is to take part in international research projects (e.g. EU-projects Pendant and SafetyNet) and use the knowledge and experience acquired from such projects.

Analysis of the Origin of Accident and Consequences

In addition to the collection of information on accidents, the investigation method (VALT Method 2003 [1]) contains the method for analysing the origin and consequences of the accident. The analysis is based on information collected by the team members and the same members carry out the analysis as a part of the investigation.

In the analysis of the origin of an accident, several questions can be asked, depending on what the goal of the investigation is. The goal in Finnish road accident investigation is to prevent accidents from happening altogether and to prevent serious consequences. The following questions and relating concepts are used to help to clarify the origin of the accident and its consequences:

- What happened? Description of the accident and key event.
- Why did it happen? Immediate and background risk factors.
- Why were there serious consequences? Injury risk factors.
- How could similar incidents be prevented? Preventative possibilities and safety recommendations.
- How could consequences be prevented in a similar case? Protection of occupants and other persons involved (pedestrians, bicyclists).

According to this investigation method, the origin of the accident is described using the following terms: key event, immediate risk factors and background risk factors (Figure 1). The origin of injuries is explained with risk factors which contributed to the serious consequences (injury risk factors). Preventative possibilities and safety recommendations are analysed in connection with each risk factor. The key event, risk factors and safety recommendations are coded into the database.

The investigation teams decide which of the parties of the accident had the most crucial effect on the origin of the event and which is then called the A-party. possible collision partner is called the B-party, the next one the C-party and so on. The question is particularly about the origin of event, and not about the seriousness of the consequences. In addition, the involvement is not

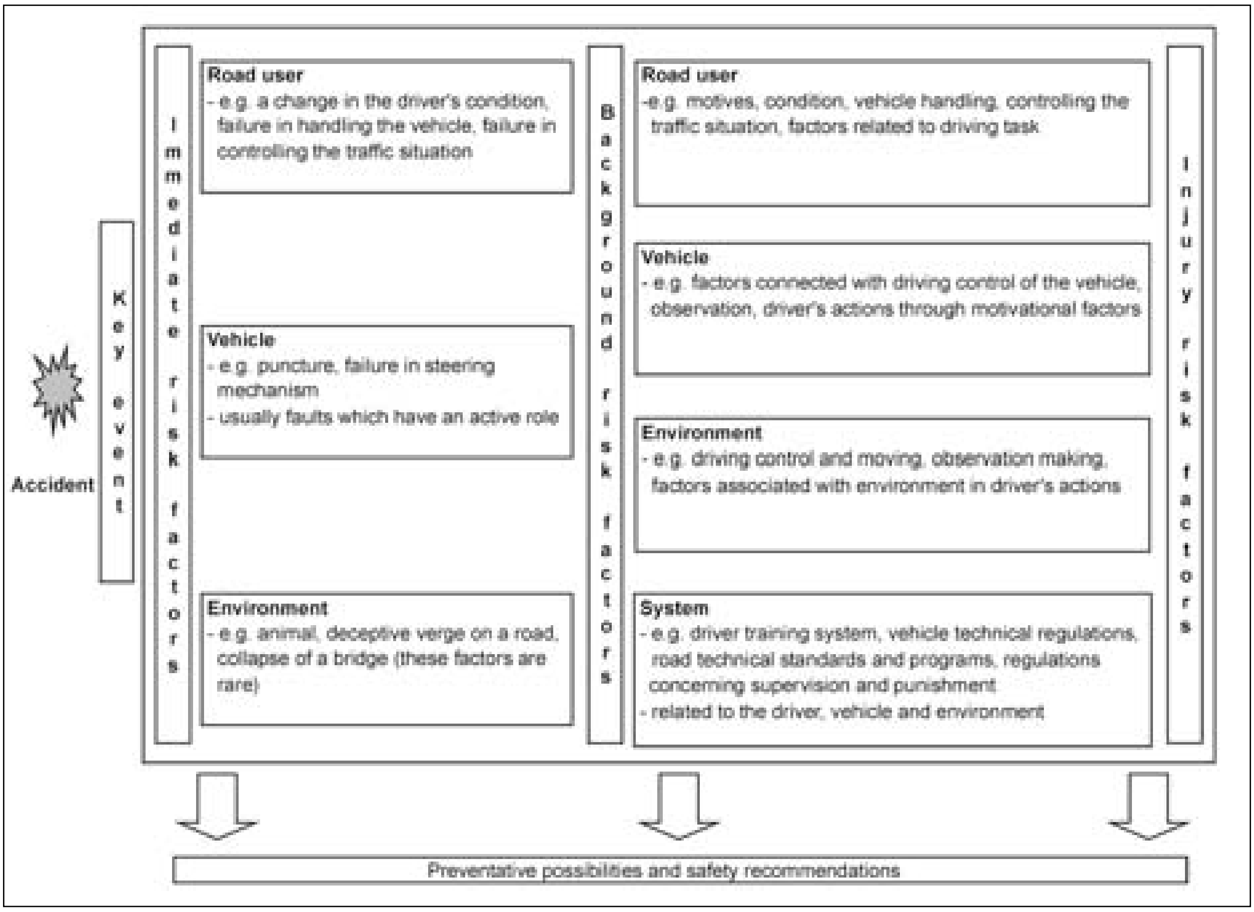


Figure 1: Risk accumulation model in investigation team investigations (adapted from the VALT method 2003)

determined based on the traffic offences (guilt) but factors which contributed to the origin of the accident.

Key event

A key event is an event that takes place immediately before the accident, either a change or a deviation in the normal flow of traffic which leads to an accident. A description of the key event always includes a description of the situation and environment, in other words, what took place and where. The idea is to distinguish in the analysis an accident event from the factors which explain its origin. In this way it is a simplified description of an event which made the crash possible. Examples of key events are: a vehicle drifting left in front of an approaching bus on a straight road; driving to a crossing line when a vehicle approaches from the right; drifting across the road to the right on a left-turn corner. In previous versions of the method, the key event included explanations of the causes of the accident which in this revised method are called immediate and background risk factors.

Risk factors

Risk factors are divided into two categories: those which contributed to I) the origin of the accident (immediate risk factors and background risk factors) and II) serious consequences (factors which have contributed to the consequences, injury risk factors). Each member examines the risk factors related to their own expert area. The members are also encouraged to look for risk factors beyond their own expert area. The description of risk factors must be in as much detail as possible so that all information collected may be retained for later research. Risk factors can hardly be described in too much detail.

I) Risk factors which contributed to the origin of the accident

The key event is explained by risk factors. The risk factors in turn are conditions or influential factors that regulate what kind of events are possible or probable.

Immediate risk factors are direct, active factors which have had an effect in the situation. Usually only one immediate risk factors can be defined for a party. The immediate risk factors can be found from three different areas:

1. Road user (a change in the driver's condition, [e.g. seizure, intentional action, falling asleep, etc.]; failure in handling the vehicle [e.g. steering mistake, braking mistake etc.]; failure in controlling the traffic situation, [e.g. wrong assessment, observational error, mistake in interpretation etc.]).
2. Vehicle (usually faults which actively have an effect on the steering of the vehicle or preventing its control, braking etc. These include puncture and failure in steering mechanism, for example).
3. Environment (include e.g. an animal running on the road, a deceptive verge on a road and a collapse of a bridge. These risk factors are rare).

Background risk factors in turn explain the origin of an immediate risk factor or key event. There can be, and usually is, several background risk factors behind an accident and for each party involved.

The question asked after finding a risk factor is why the risk in question may have materialised or may have been in existence. This procedure is repeated with the risk factors found. This way an attempt is made to progress at least to the depth of a few risk factors even though in reality it is natural that the chains of this kind never end. However, the objective is to also get to the level of the more general traffic system, and even community factors. The idea is that the problems of traffic safety are not only problems of traffic, let alone problems of the parties involved.

The risk factors interact with each other. The probability of the accident may increase particularly from the effect of a combination of several risk factors. Because it is difficult to get information about the interactions of risks, they are as a rule defined and their effect is estimated one by one. The investigation team presents in its risk investigation the combination of the most important risk factors that have had an effect in an accident, in which the interactivity of risk factors emerges.

The background risks, by their existence or omission, contribute to the origin of the accident; they are pre-conditions for the accident but do not necessarily lead to an accident. The risk factors in the background can be found from four different areas:

1. Road user (factors connected with road user's motives, condition [e.g. alcohol, tiredness, stress, showing off]; vehicle handling [e.g. incorrect methods for handling the vehicle]; controlling the traffic situation [e.g. choice of speed, inexperience in controlling a traffic situation]; factors related to the driving task [e.g. haste, nature of driving task, planning the drive, effect of companion on the trip]).
2. Vehicle (factors connected with the driving control of the vehicle [e.g. tyre pressures, loading, wind sensitivity]; observation [e.g. shades, passengers, lights, reflectors]: driver's actions through motivational factors [e.g. capacity of the car and its properties]).
3. Environment (factors connected with driving control and moving [e.g. potholes, driving ruts and slippery road]; making observations [e.g. poor visibility, darkness, rain]; factors associated with the environment in driver's actions by steering, doing tricks or possibly acting in a way that in turn increases the risk [e.g. poor visual guidance, a deviating bend on an otherwise straight section of the road, a speed limit that is too high for the visibility needed]).
4. System (risk factors at the system level assessed in an investigation include the following examples and typically have an effect behind the background factors and they are related to the driver, vehicle and environment [e.g. driver training system; the system for monitoring the driver's ability; vehicle technical regulations; regulations concerning vehicle inspection and their implementation; road technical standards and programs; programs related to road maintenance; regulations concerning supervision and punishment; regulations and operating principles applied to public transport; responsibilities of transport carriers; local politics]).

II) Risk factors which contributed to the consequences (injury risk factors)

Factors which caused the damage and injuries, or permitted them, are considered risk factors which are related to the seriousness of the consequences of the accident (injury risk factors). In that case, the point of view will not be in the origin of the accident event but in factors which are related to the vehicle and the traffic environment and which increase the seriousness of the consequences of the accident. Examples of these vehicle related risk factors could be of large difference in size, weak bodywork, aggressiveness of the collision partner, loading and vehicle structures that penetrate the vehicle. Corresponding factors in the environment are, for example, inflexible collision obstacles (rocks, trees, posts, cuttings) and missing railings. The investigation teams also analyse risk factors connected with the use of safety equipment related to the injuries.

Preventative possibilities and safety recommendations

Producing safety recommendations is an important part of the investigation method. When investigation teams draft their recommendations they seek to find ways of preventing both the crash and serious consequences (death and injuries). The starting point for the proposals for safety recommendations is an attempt to find the preventative possibilities in each immediate and background risk factor. An example: a vehicle moving to the opposite lane in front of an oncoming vehicle because the driver fell asleep. The preventative possibility would then be for example, that the movement to the opposite lane should be prevented, and as a safety recommendation, central railings to separate the opposite directions and devices which examine the drivers alertness could be suggested. Ideas for safety recommendations can also be found further away, e.g. according to falling asleep it could be suggested that more focus should be put on driving time regulations in commercial traffic.

Preventative possibilities can be examined with the help of reconstruction, for example, by calculating the speed at which those involved should have been travelling in order to be able to stop before the impact or give way taking into account visual obstructions, weather, detection of the pedestrian, etc. This creates opportunities to consider ways of achieving this safer alternative and produce safety recommendations.

Risk factors and safety recommendations are connected with each other. Thus, a safety recommendation (or many safety recommendations) is produced for each risk factor. Likewise, each safety recommendation has to have a risk factor to which it is connected. Safety recommendations are systematically produced from the same four areas from which the risk factors can be found: road user, vehicle, environment and the system.

Not too much attention should be paid to the feasibility of the proposals, as many of the ideas that would not have been thought possible in the past, such as airbags or "smart tyres", are reality today. The investigation teams produce many versatile ideas whose significance then can be shown in connection with several accidents. Each member of the team produces safety recommendations related to its own expert area and also looks for safety recommendations beyond its own expert area.

Results of Investigation

Investigation report

When all the relevant information is collected and obtained from different sources, the investigation team meets in a final meeting where all the material is available. Based on the process described above, the investigation team combines the results of the investigations and the analysis of the accident and writes an investigation report. The investigation report is usually a consensus report, which is written after discussion and argumentation. The report is written in a standard form. The investigation report is a public document and contains no identification data.

Investigation folder

An investigation folder contains the investigation report, investigation forms completed by all members, sketches, photographs, reconstructions, documents concerning the records of post mortem and pre-investigation protocols of the police. Other relevant documents may also be included. The folder is put together after the investigation is completed and filed with the Finnish Motor Insurers Centre where the information is coded into a computer database. The average duration of an investigation is 6 months. The time depends, among other things, on when the pre-investigation protocols and autopsy statements are completed.

Use of collected data

Both the investigation folders and the accident database are available for researchers and authorities free of charge for road safety purposes. The data is used for publishing an annual report and four quarterly preliminary reports and a preliminary report of alcohol related accidents. The collected information and results of analyses are used in research, education, training, reporting, statements, policy making and in other traffic safety work in Finland. The findings of the investigation teams and the studies done based on the collected material have influenced Finland's Road Safety Programmes. The data has also been used in journal articles [e.g. 14, 15, 16, 17, 18, 19] and international research projects (e.g. Pendant). The investigation teams can also inform authorities about vehicle and road defects that require immediate actions.

Discussion and Conclusions

The road accident investigation teams form an essential part of Finnish road safety work and the collected, detailed and disaggregated data are widely used when making new proposals to improve road safety. The collected data also give good possibilities to do e.g. follow-up research, as the system has been active for over 30 years. A point worth mentioning is also that the sampling does not create problems when fatal accidents are concerned as all fatal road accidents are investigated and this fact makes the data a convincing source of information.

The investigation method has also been implemented in investigating other than fatal accidents, that is, accidents leading to injuries or damage-only accidents (for example, heavy vehicle accidents, snowmobile accidents, accidents where a new vehicle has been involved). With these kinds of projects, the risk factors, preventative possibilities and safety recommendations according to other than fatal accidents may be revealed.

In-depth on-the-spot road accident investigation is essential, when the goal for investigation is to find out how the accident happened, what the risk factors were, why there were serious consequences and how similar incidents could be prevented from happening again. These kinds of goals mean of course, that the investigation of accidents requires a lot of resources and is time-consuming.

When the teams investigate accidents, although on-the-spot, the investigations are always retrospective as the accident has already happened. This makes the data collection challenging and some missing information cannot be avoided. The great number of investigated accidents still makes it possible to do research based on the data.

The experiences of the investigation teams, their work and the results of the work give every reason to say that the work has proved that it serves a purpose not only as a source of data on road accidents but also as a detector of defects in traffic systems and as an initiator of measures taken to launch improvements. The collected information and the research done based on it keep the safety authorities abreast of developments, strengthen co-operation and help decision-making concerning road safety issues.

References

1 VALT Method 2003: Finnish Motor Insurers' Centre, Helsinki, 2004

2 L. LARSEN: Methods of multidisciplinary in-depth analyses of road traffic accidents, Journal of Hazardous Materials, 111, 115-122, 2004

3 L. LARSEN, P. KINES: Multidisciplinary in-depth investigations of head-on and left-turn road collisions, Accident Analysis and Prevention, 34, 367–380, 2002

4 A. ENGLUND, B. JARLERYD, O. LINDKVIST, H.E. PETTERSSON: TRK's haverikomission. Redogörelse för en försöksverksamhet (Rapport nr 1), Stockholm, 1978

5 K. MIDTLAND, R. MUSKAUG, F. SAGBERG: Evaluering av Vägverkets havariundersøkelser, Transportøkonomisk institutt, Rapport 296, Oslo, 1995

6 Swedish Road Administration, http://www.vv.se/filer/2586/djupstudier_eng_4.pdf

7 J. SANDIN, M. LJUNG: Crash investigations for active safety – Meeting new demands on investigation methodology, The paper was presented at the 1st International Conference on ESAR – Expert Symposium of Accident Research, Hannover, Germany, September, 2004

8 J. HILL, R. CUERDEN: Development and Implementation of the UK On The Spot Accident Data Collection Study – Phase I, Department for Transport, Road Safety Research Report No. 59, London, 2005

9 H. JÄHI, G. VALLET, L. CANT, C. BRACE, L. RACKLIFF, M. PAGE, G. GIUSTINIANI, P. ALOIA, D.S. USAMI, A. LALLANA, D. OTTE, M. JÄNSCH, K. PARKKARI, D. MARGARITIS, Y. de VRIES: SafetyNet Deliverable D4.2 Database Transparency, 2006

10 K. THIRIEZ, G. RADJA, G. TOTH: Large Truck Crash Causation Study – Interim Report (DOT HS 809 527), Washington, D.C., 2002

11 FARS, Fatality Analysis Reporting System, http://www-fars.nhtsa.dot.gov/

12 R. PAULSSON: SafetyNet Deliverable 5.2 In-depth Accident Causation Data Study Methodology Development Report, 2005

13 Act on the investigation of road and cross-country traffic accidents (No. 24/2001) and the Council of State decree (No. 740/2001), Helsinki, 2001

14 L. HAKAMIES-BLOMQVIST: Fatal accidents of older drivers, Accident Analysis and Prevention, 25, 19-27, 1993

15 L. HAKAMIES-BLOMQVIST: Compensation in older drivers as reflected in their fatal accidents, Accident Analysis and Prevention, 26, 107-112, 1994

16 K. HERNETKOSKI, E. KESKINEN: Self-destruction in Finnish motor traffic accidents in 1972–1992, Accident Analysis and Prevention, 30, 697-704, 1998

17 S. LAAPOTTI, E. KESKINEN: Differences in fatal loss-of-control accidents between young male and female drivers, Accident Analysis and Prevention, 30, 435-442, 1998

18 S. RAJALIN, H. SUMMALA: What surviving drivers learn from a fatal road accident, Accident Analysis and Prevention, 29, 277-283, 1997.

19 N. VIRTANEN, A. SCHIROKOFF, J. LUOMA, K. KARKOLA, J. SALO: In-depth evaluation of the effects of automatic emergency call system on road fatalities. Submitted to Accident Analysis and Prevention, 2006

C.Y. Kong, J.K. Yang, L. Li
Hunan University, Changsha, China

W.Q. Li, Z. Zhao
WuJing Hospital, Changsha, China

D. Otte
Hannover Medical University, Germany

In-Depth Investigation of Vehicle Traffic Injuries in Changsha of China[1]

Abstract

This study aimed to identify the occurrence, type and mechanisms of the traumatic injuries of the vulnerable road users in vehicle collisions, and to determine the effects of human, engineering, and environment factors on traffic accidents and injuries.

The pedestrian accident cases were collected in the years 2000 to 2005 from Changsha Wujing hospital China and Accident Research Unit at Medical University Hannover in Germany. A statistic analysis was carried out using the collected accident data. The results from analysis of Changsha data were compared with results from analysis of GIDAS data Hannover.

The injury severities were determined using AIS code and ISS values. The results were presented in terms of cause of injuries, injury distributions, injury patterns, injury severity. The factors influenced the injury outcomes were proposed and discussed for the vehicle transport environment and road users. The results were discussed with regard to accident data collection, accident sampling and injury distributions etc.

In the urban area of Changsha, motorcycles and passenger cars are most frequently involved in vehicle pedestrian accidents. Head and lower extremities injuries are the predominant types of pedestrian injuries. The pedestrian accidents were identified as vital issue in urban traffic safety and therefore a high priority should be given to this road user group in research of safe urban transportation.

In Hannover area, cars are most frequently involved in traffic accidents, injured pedestrians are involved in road traffic of Germany in 13% of all causalities only in 2005 and have nearly the same number as motorcyclists, but the half of bicyclists.

1 Introduction

In China 107,000 road users are killed and 549,051 are injured in 2004, resulting in substantial economic losses due to fatalities and long-term consequences. The social cost was found as high as 3,090 millions RMB, which clearly demonstrates the urgent demand for preventive measures.

In Germany 440,000 road users were injured in 2004, the half of these were aged between 25 to 65 years old, 5,800 fatalities could be registered in that year, 14% were pedestrians [1].

Pedestrians represent a high risk population since they are unprotected in vehicle impacts, they are one of the most vulnerable road users in city traffic. About 25,000 pedestrians are killed in traffic accidents each year recently in China [2]. In the European Union (EU) 7,000 pedestrians are killed each year, 5,000 in the USA, about 3,000 in Japan. Within the EU countries, the relative frequency of the pedestrian fatalities varies remarkably from 14% in Sweden to 32% in UK. Pedestrian protection is therefore a priority item in traffic safety strategies of nearly all countries world-wide [3].

The objective of this study is to identify the occurrence and type of the traumatic injuries of the relatively unprotected vulnerable rod users especially the situation of the pedestrians in vehicle collisions, and to investigate the correlation of traffic injuries with human factor and engineering, environment factors, by using valid and reliable materials collected from local hospital and traffic administration authorities. The knowledge from the study is a prerequisite for developing guidelines to improve pedestrian safety and with this perhaps the safety for all other kind of vulnerable road users.

2 Method and Materials

A study of vehicle pedestrian accidents was conducted by using the collected accident data of different in-depth investigation activities in both the countries China and Germany. The data consists of two parts: one part of the data with 403 pedestrian

1 Natural Science Foundation of China (NSFC 10472031)
Corresponding Author: JikuangYang@hnu.cn

accident cases was collected from Wujing Hospital in Changsha, China; another part of the data with 407 cases was collected from GIDAS database documented at the Accident Research Unit in the Medical University Hannover, Germany.

Firstly, a general statistic analysis was carried out using 403 cases from Changsha in terms of cause of injuries, injury distributions, injury patterns, and injury severity. Secondly, 72 cases of 403 pedestrian accidents were selected with detailed injury descriptions for analysis of pedestrian injuries using AIS code and ISS value. Thirdly, 407 pedestrian accident cases collected from the accident database GIDAS (German In-Depth Accident Study) Hannover were used for an in-depth analysis of pedestrian injuries. Finally, a comparison was carried out in terms of analysis results based on accident data from Changsha and Hannover. The factors influencing the injury outcomes were proposed and discussed in terms of vehicle transport environment and road users. The results were discussed with regard to accident data collection, accident sampling and injury distributions etc.

2.1 Accident data collection

2.1.1 Accident data from Wujing Hospital in Changsha

The Wujing hospital is located in urban area of Changsha (Figure 1) and specialized in dealing with emergency cases in traffic accidents. The hospital admits the patients with traffic trauma in the urban area in Changsha with a population of 2,060,000 (6,133,000 including residents in suburb) and registered vehicles of 255,599 in 2000.

An in-depth study on the hospital clinical documentations for 622 traffic injury patients from 2000 to 2005 was carried out in cooperation between researchers and medical doctors. 403 cases were collected based on the study of the clinical report. The hospital data are summarized according to accident date, patient age, gender, and available information about pedestrian injuries, as well as type of accident vehicles. Pedestrian accident data were also collected from traffic administration authorities with information about accident sites and vehicles based on accident report. 72 pedestrian cases were selected from the well documented 403 cases with detailed description of the injury patterns, and injury severities. The GCS code and the AIS [4] code were used to determine the injury severity. The situation of treatment period and healing was studied based on hospital documentations to identify the consequence of accident.

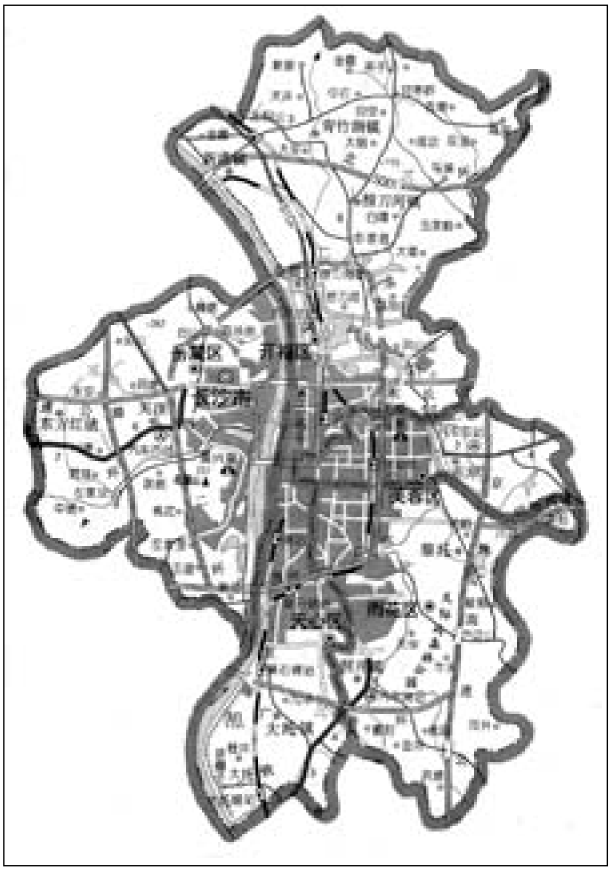


Figure 1: The urban area of Changsha, the capital of Hunan Province located in the south middle of China

Furthermore, 825 pedestrian accident cases in 2005 were collected from the Traffic Police Station in Changsha. A preliminary statistics analysis was carried out to identify the type of pedestrian accidents in terms of involved vehicles.

2.1.2 GIDAS accident data from Hannover Medical University

In the district of Hannover a representative sampling of accidents was carried out by the order of German Government (Federal Highway Research Institute BASt) in cooperation with the car manufactures FAT since the year 1999 (OTTE et al., 2003). In the area of Hannover nearly 1,000 accidents with injured person are collected there annually in a continued and representative way. These accident cases were documented in the accident database GIDAS (German In-Depth Accident Study) by the Accident Research Unit at the Medical University of Hannover. The collected cases in the GIDAS database contain very detailed information about pedestrian victims on age, gender, height/weight, injuries, speed determination and details of the accident cars as well as the accident scene issues.

Altogether 407 vehicle-to-pedestrian accident cases from the GIDAS database were collected based on the following standards: (1) the pedestrian should sustain at least an AIS 1 injury; and (2) the accident occurred during the period from 2000 to 2005.

3 Results and Analysis

3.1 Involvement of vehicles

Considering vehicle types involved in accidents, the pedestrians were struck in Changsha most frequently by motorcycle and passenger car. Figure 2a shows approximately 43.9% of the accidents are motorcycle-pedestrian collisions, and 34% car, 4.2% truck, and 3.5% bicycle. Figure 2b shows approximately 14.7% of the accidents are motorcycle-pedestrian collisions, and 58.4% car, 12.7% bus, 12.2% truck, and 1.3% bicycle. Compared to China´s situation for Germany there can be registered mainly car involvement in pedestrian collisions (80.6%) (Figure 2c).

3.2 Frequency of pedestrian accidents

An analysis of frequency of pedestrian accidents was conducted with the collected data in terms of age groups, gender and injured body parts.

3.2.1 Age distribution in pedestrian accidents

Figure 3a illustrates the age distribution in pedestrian accidents for Changsha. 7.9% of injured pedestrians are children under 15 years old. The pedestrians under 20 years old accounted for 18.1%. 71.9% of pedestrians involved in an accident were adults from 21 to 60 years old and formed the big group. Elderly pedestrians 60 years old and above accounted for 9.9% of all injured pedestrians.

Figure 3b illustrates the distribution in pedestrian accidents for Hannover in different age groups: 32,5% for child pedestrians under 15 years old, 42,3% for pedestrian under 20 years old, 36,4% for 21-60 age group, and 21,4% for older pedestrians >60 age group.

It can be seen that in Germany the highest risk exsiting for young and old pedestrians, compared to this in China the adult group of 20 to 50 years old is injured mainly.

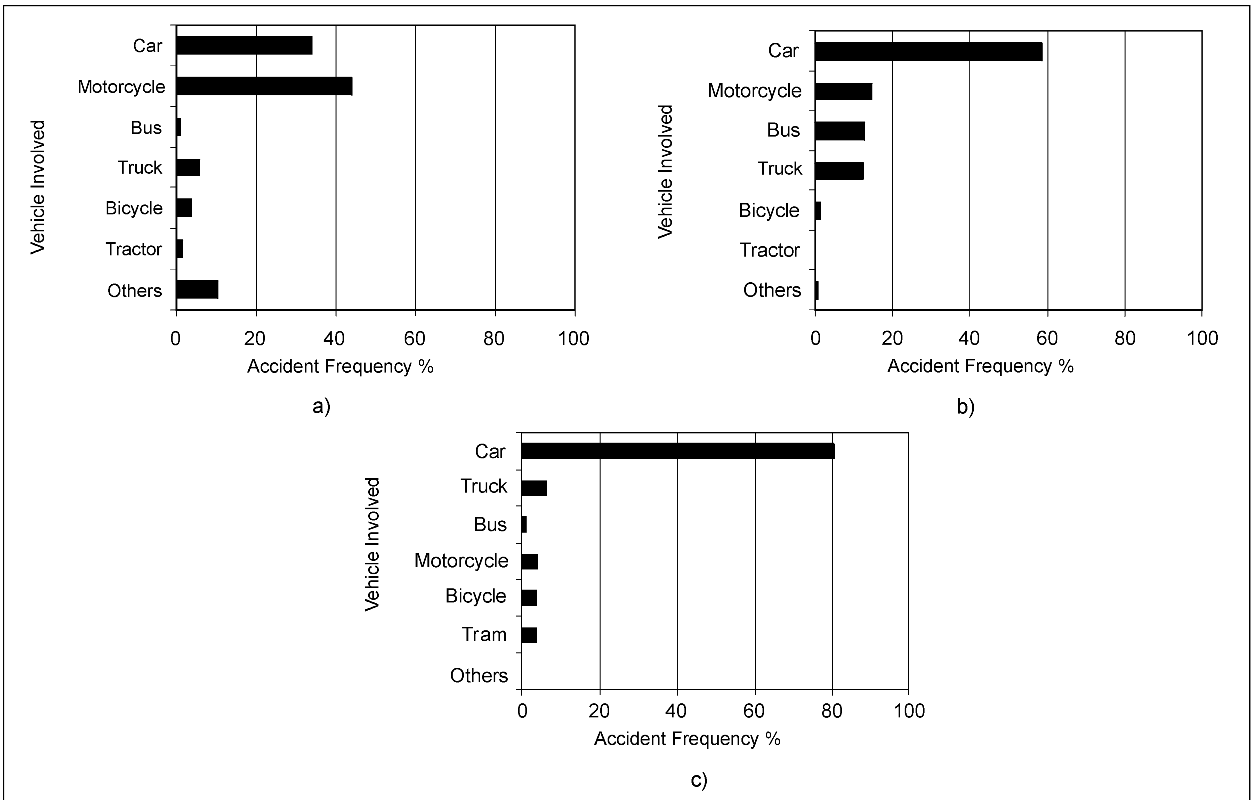


Figure 2: Frequency distribution of vehicle type in pedestrian accident: (a) 825 cases from Changsha Traffic Police Station, (b) 403 cases from Changsha Wujing hospital, and (c) 407 cases from GIDAS Hannover

3.2.2 Gender distribution in pedestrian accidents

Table 1A and 1B present the results for the age distribution of injured pedestrians in terms of gender. Of the Changsha pedestrians, 67% of the pedestrians are male and 33% are female. Of the Hannover pedestrians, 51.9% are male and 48.1% are female. We noted that the male pedestrians encounter in both countries for higher risks than that for females in vehicle accidents.

3.2.3 Distribution of injury frequency by body parts

Figure 4a presents the results for the distribution of injured body parts from Changsha cases. The head and lower extremities were found to be the most frequently injured [4]. Of the total pedestrian patients, 31.5% suffered head injuries. The lower extremity injuries accounted for 32.8%, and upper extremities 9.4%. In pedestrian accidents chest and pelvis injuries also took a significant proportion of

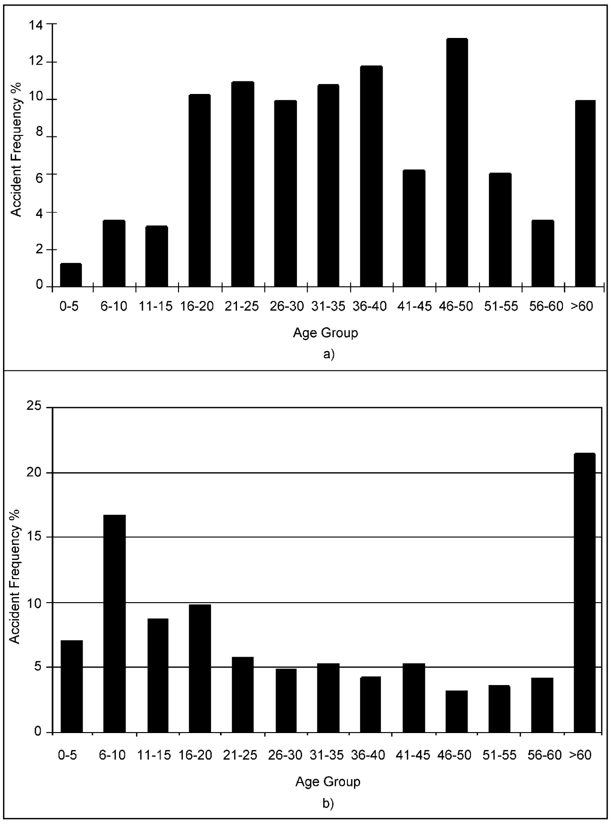


Figure 3: Frequency distribution of age group in pedestrian accident (a) 403 cases from Changsha Wujing hospital, and (b) 206 cases from GIDAS Hannover

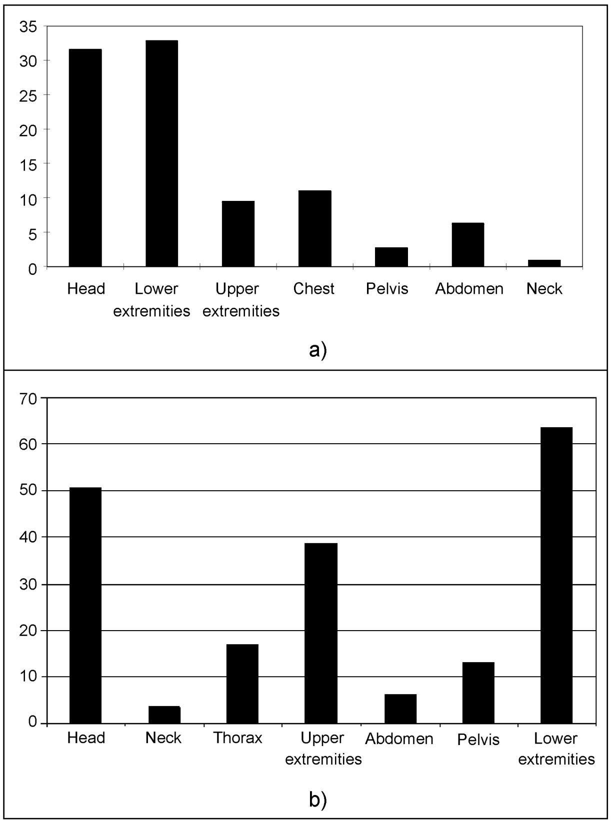


Figure 4: Distribution of injury by pedestrian body regions (a) Changsha, and (b) GIDAS Hannover

Age	0-15yr		16-60yr		>60yr		Total	
Gender	Number	%	Number	%	Number	%	Number	%
Female	13	40.6	101	30.5	19	47.5	133	33.0
Male	19	59.4	230	69.5	21	52.5	270	67.0
Total	32	100	331	100	40	100	403	100

Table 1A: Distribution of pedestrian age and gender in traffic accidents (Changsha)

Age	0-15yr		16-60yr		>60yr		Total	
Gender	Number	%	Number	%	Number	%	Number	%
Female	49	38.3	89	48.7	56	61.6	194	48.1
Male	79	61.7	97	51.3	37	38.4	213	51.9
Total	128	100	186	100	93	100	407	100

Table 1B: Distribution of pedestrian age and gender in traffic accidents (GIDAS Hannover)

13.5% of all injuries. Abdominal injuries were found in 6.2%, and neck injuries were relatively rare, in 0.8%.

Figure 4b presents the distribution of injured body parts for Hannover GIDAS data. 50.7% suffered head injuries. The lower extremity injuries accounted for 63.5%, and upper extremities 38.7%. In pedestrian accidents chest and pelvis injuries also took a significant proportion of 17.1% for the thorax and 13.0% for the pelvis. Abdominal injuries were found in 6.3%, and neck injuries were relatively rare, in 3.6%. The injury distribution is similar between China and Germany, the head and the legs are the major exposed injured body parts, in Germany a higher injury risk of the arms can be seen in the diagrams.

3.3 Severity and distribution of pedestrian injuries

For an in-depth study of pedestrian injuries 72 Changsha cases were selected from the Wujing Hospital with a sampling defined as follows: (1) the injuries were described with very detailed information which can be used to determine the injury severity with AIS code; (2) the pedestrian should sustain at least an AIS 1 injury; and (3) accident occurred during the period from 2000 to 2005.

3.3.1 AIS coding and analysis

The severity of injury sustained by individual body area is given in Table 2. The percentage is that the number of body segment injuries refer to the total number of registered injuries by injury severity. With the detailed information of 72 cases from Wujing hospital, the injuries are rated on the AIS scale [5]. The overall injury severity classified with AIS code is summarized in Table 2A. 59.7% of the cases with AIS 1 and 2 minor/moderate injuries, and 25% with serious injuries, the severe and critically injured pedestrians are 9.7% and 5.6%, respectively. It was found that head and lower extremities were, again, the body parts most frequently injured. From the clinical documentation in Wujing hospital we noted that the head injury patterns are skull fractures and brain injuries, including cerebral concussion, lacerations, contusion, and intracranical hematoma. The common thorax injury patterns are rib fractures with hemoth and pneumoth. The leg injuries are more frequent than upper thigh fractures including the toe, tibia, fibula fracture. The pelvis injuries are parenchyma contusion.

Injury Severity	MAIS	Number	%
Minor	1	3	4.2
Moderate	2	40	55.5
Serious	3	18	25.0
Severe	4	7	9.7
Critical	5	4	5.6
Fatal	6	0	0
Total	_	72	100

Table 2A: Injury severity of pedestrians in 72 selected cases (Changsha)

Injury Severity	MAIS	Number	%
Minor	1	231	68.3
Moderate	2	116	22.5
Serious	3	36	6.2
Severe	4	7	1.0
Critical	5	13	1.6
Fatal	6	4	0.5
Total	-	407	100

Table 2B: Injury severity of pedestrians in 206 collected cases (GIDAS Hannover)

With the detailed information of GIDAS Hannover, the overall injury severity classified with AIS code is summarized in Table 2B, 90.8% of the cases with MAIS 1 and 2 minor/moderate injuries, and 6.2% with MAIS 3 serious injuries. The severe and critically injured pedestrians (MAIS 5/6) are 2.1%.

The compared injury distribution between Changsha/Hannover shows the different sampling criteria, the data of Hannover consider the whole injury distribution in a statistical manner (minor to fatal). Changsha cases are representing the situation of a hospital, therefore directly died persons at the scene (MAIS 6) are not included.

3.3.2 ISS value and analysis

The ISS value was calculated for the selected 72 cases from Changsha and 206 cases from GIDAS. Table 3 presents the calculated ISS values.

The injury severity grade ISS is a good predictor for the whole severity of the injured body related to the complexity of treatment and the outcome of survival. It can be seen that the german injured pedestrians have a better injury outcome, 91.7% suffered ISS <10. A polytraumatized victim with risky treatment starts at ISS values above 15. In

Germany those cases can be seen in 3.3% compared to China in 16.6%.

ISS	Changsha data		GIDAS data		Severity
	N	%	N	%	
< 10	53	73.6	350	91.7	Minor
10-15	7	9.7	28	5.0	Moderate
16-19	7	9.7	5	0.8	Serious
20-39	5	6.9	11	1.4	Severe
40-66	0	0	5	0.6	Critical
75	0	0	4	0.5	Fatal
Sum	72	100	403	100	-

Table 3: Correlation of injury severity with ISS value

3.3.3 Analysis of injury severity by body regions

Injury severity	Slight, AIS<3 (N=43)		Serious, AIS=3 (N=18)		Fatal, AIS>3 (N=11)		Total (N=72)	
Body segment	Injury	%	Injury	%	Injury	%	Injury	%
Head	23	67.6	2	5.9	9	26.5	34	100
Face	9	100	0	0	0	0	9	100
Lower extremities	24	66.7	12	33.3	0	0	36	100
Upper extremities	3	100	0	0	0	0	3	100
Chest	6	66.7	3	33.3	0	0	9	100
Pelvis	3	100	0	0	0	0	3	100
Abdomen	3	60	2	40	0	0	5	100
Neck	0	0	0	0	0	0	0	0

Table 4A: Distribution of injury severity by pedestrian body regions (Changsha)

Injury severity	Slight, AIS<3 (N=347)		Serious, AIS=3 (N=36)		Fatal, AIS>3 (N=24)		Total (N=407)	
Body segment	Injury	%	Injury	%	Injury	%	Injury	%
Head	192	94.0	7	1.9	15	3.1	214	100
Lower extremities	232	92.2	30	7.5	1	0.3	263	100
Upper extremities	144	97.5	6	2.5	0	0	150	100
Chest	62	85.8	6	5.2	13	9.0	81	100
Pelvis	54	97.7	1	0.4	2	1.9	57	100
Abdomen	24	91.7	1	1.0	3	7.3	28	100
Neck	15	87.4	0	0	3	12.6	18	100

Table 4B: Distribution of injury severity by pedestrian body regions (GIDAS Hannover)

3.3.4 Analysis of injury severity in age groups

Age	0-15yr		16-60yr		>60yr		Total	
MAIS	Number	%	Number	%	Number	%	Number	%
1	1	16.7	2	3.4	0	0	3	4.2
2	1	16.7	35	60.3	3	37.5	39	54.2
3	1	16.7	12	20.7	5	62.5	18	25
4	2	33.3	6	10.3	0	0	8	11.1
5	1	16.7	3	5.2	0	0	4	5.6
6	-	-	-	-	-	-	-	-
Total	6	100	58	100	8	100	72	100

Table 5A: Distribution of injury severity by age group (Changsha)

Age	0-15yr		16-60yr		>60yr		Total	
MAIS	Number	%	Number	%	Number	%	Number	%
1	81	72.4	110	71.6	40	54.8	231	68.3
2	40	23.2	47	18.8	29	29.3	116	22.5
3	6	4.0	17	6.0	13	10.0	36	6.2
4	0	0	3	0.9	4	2.6	7	1.0
5	1	0.4	7	2.1	5	2.3	13	1.6
6	0	0	2	0.5	2	1.1	4	0.5
Total	128	100	186	100	93	100	407	100

Table 5B: Distribution of injury severity by age group (GIDAS Hannorver)

In all age groups the injury risk is very high for the China situation compared to the German situation. Nearly three-quarter of the Hannover pedestrians suffered injury severity grades MAIS 1 only, except the older age group of >60 years old (54.8%). 26.0% were MAIS 3+ injured. Compared to this 62.5% of the > 60 years old pedestrians were MAIS 3+ injured in Changsha. A very low number of minor injured pedestrians could be registered there in all age groups.

4 Discussion

4.1 Causation of injuries

The vehicle traffic accidents steeply increased in the past decade world-wide therefore in China as well as in Germany. But the injury situation related to traffic accidents seems to have different pictures for Germany and China. The annually fatalities in the reported accidents of China increased from 49,271 in 1990 to 107,000 in 2004. The road traffic authority made large efforts to control the incidence of the accidents, but the tendency of the accident growth is still a critical issue in China. Particularly, the fatalities of vulnerable road users formed a

Body region	China (Changsha) (%)	GIDAS (%)	Europe (%)	Australia (%)	Japan (%)	USA (%)
Head	31.5	26.4	29.8	39.3	28.6	32.7
Face*	5.8	-	5.3	3.7	2.4	3.7
Neck	0.8	2.2	1.8	3.1	4.5	0.0
Chest	10.9	10.0	11.6	10.4	8.5	9.5
Abdomen	6.2	3.5	3.8	4.9	4.8	7.7
Pelvis	2.6	7.0	7.9	4.9	4.5	5.3
Upper extremities	9.4	18.5	8.1	8.0	9.0	7.9
Lower extremities	32.8	32.4	31.3	25.8	37.2	33.3
Unkown	0.0	-	0.5	0.0	2.1	0.0
Total	100	100	100	100	100	100
* not distinguished from head injuries						

Table 6: Comparison of percentage distribution of pedestrian injuries by body region

main proportion of all reported fatalities in traffic accidents. For instance about 12,500 pedestrians were killed in 1990, and 26,000 in 2001, which accounted for about 26% of all traffic fatalities annually. Compared to this, for Germany the number of causalities could be reduced over the last 30 years continuously to a total number of currently 5,361 in 2005. The percentage of fatal pedestrians built 13% on that total number.

The present study is based upon an analysis of 403 accidents in urban area of Changsha in China and the area of Hannover in Germany. The evaluation method was described and the available accident data were analyzed. The used samples are small, but as a preliminary study the presented methodology for an comparison of different in-depth accident studies could be used for comparison of the injury risk and injury outcome for different countries. Such methodology can be used for further studies with new collection of accident data in the area and special research issues.

It was found that the present results are quite comparable to results from studies by other researchers. For instance, the pedestrian accident is a common problem in both motorized countries and motorizing countries, which occur frequently in city build up areas, but the injury risk for pedestrians in Germany can be seen as much less dangerous as in China. On the other hand the combined results of the in-depth analysis of the two different areas of China and Germany shows major resources for further countermeasures on car safety developments, i.e. young and old pedestrians need to be focussed on in Germany, adult pedestrians 20 to 50 years old need to protected more in China. The finding of the frequency in age distribution is quite different from that in other motorized countries. Child pedestrian accidents accounted for 25.3% in the USA, 33.1% in Europe, and 34.2% in Japan. A further study is needed to identify the factors which affect the different results.

Pedestrian accident analyses have been conducted worldwide in the past four decades [5-10]. Pedestrian impact conditions and injury outcomes were identified from these studies. The findings of the distribution of pedestrian injuries to different body segments are compared between the results from this study and results from published studies by other researchers world-wide as presented in Table 6, showing the distribution of injured body regions (100%). As a common tendency, the head and the lower extremities have been found to be the most frequently injured body regions.

The analysis of pedestrian accidents in Changsha indicated that motorcycles and passenger cars are most frequently involved in vehicle-pedestrian accidents compared to Germany where the major collision partner of a pedestrian is a car (80.6%). 43.9% of the accidents in Changsha are motorcycle-pedestrian collisions, and 30.3% passenger-cars. In the EU countries, the number of pedestrians struck by passenger cars is around 60% to 85% of the reported vehicle-pedestrian accidents [5], and 56% of the reported pedestrian accidents are caused by passenger cars in the USA. Due to the difference of involved vehicles from country to country, the priority of safety countermeasures should be given considering the frequency of involved vehicles [12-15].

4.2 Countermeasures

Even that for Germany a good reduction of the number of fatalities and severe injured pedestrians can be registered over the last decade further measurements for safety can be seen as important, the head injury risk and the risk of lower extremities should be focused on in the future.

There is great potential of reduction of the accidents and fatalities in China by enhancing the safety consciousness of all road users, improving the traffic administration, and strictly implementing traffic laws.

It is necessary to point out that a large amount of the accidents resulted from people's mistakes. The accidents and accident casualties mainly attributed to the causation factors. This study considered not the aspects of causation, but in-depth analyses could be also a good tool for such research in different countries.

4.3 Limitations

It is also noticed that limitations existed in this study. The data sources partly reflect the real situations of pedestrians in traffic accidents in Changsha and Hannover and not in the whole countries of China and Germany. On the other hand, the used samples are influenced by their specific sampling criteria being different for Changsha and Hannover. For Changsha in some cases the medical records were not complete due to that the injured pedestrians left the hospital without continual cure and the reports could not point out whether they have healed and in the sample those fatalities were not included which died directly on the scene. Another problem existed in Changsha on the medical records providing comprehensive data on the injuries, they seldom provided exact details of the locations and extent of the injuries, and this brings up a difficulty to classify the injuries according to the AIS code. Compared to this the data of GIDAS Hannover are comprehensive and give information on every issue of accident and injury details [5].

5 Conclusions

Pedestrian accidents represent a group of vulnerable road users to high risk of unprotection, and in relation with the importance of pedestrians within the traffic of a country therefore a high priority should be given to this road user group in research of safe urban transportation.

About over two thirds of injured pedestrians are male pedestrians. The exposure of injury risks to elderly people is much higher than that to younger pedestrians. This seems to be relevant for the German situation where the major injured pedestrians could be seen. In Changsha the main focus has to be given to the adults in the age of 20 to 50 years of age. In the urban area of Changsha motorcycles and passenger cars are most frequently involved in vehicle pedestrian accidents.

The head and lower extremities injuries are the predominant types of pedestrian injuries. Chest and pelvis were frequently injured, then followed by abdomen injuries, whereas injuries to upper extremities and neck were relatively infrequent. It is necessary to give the priority of injury prevention to the head and lower extremities. Meanwhile in China many European cars are driven, therefore it can be expected that in some years the same safety standard and injury risk will be approached. Further in-depth studies may identify this common approach.

6 Acknowledgment

This study is sponsored by the Natural Science Foundation of China (NSFC 10472031). The authors would like to thank Mr. Zhimin Liu, the Director of Changsha Traffic Police, and Prof. Dietmar Otte, Hannover Medical University, for provided accident data.

References

[1] Statisitcal Data of the Statistical Bureau Germany, Wiesbaden 2005

[2] Z.G. WANG: Mechanisms for Occurance of Road Traffic Injuries. Chinese Journal of Traumatology. 1999. 15AF85-86

[3] J.K. YANG (1997): Injury Biomechanics in Car–Pedestrian Collisions: Development, Validation and Application of Human-Body Mathematical Models. Thesis for the Degree of Doctor of Philosophy. Department of Injury Prevention, Chalmers University of Technology, Gothenburg, Sweden

[4] AAAM (1998): Abbreviated Injury Scale – 1990 Revision. Association for the Advancement of Automotive Medicine, Des Plaines, IL, U.S.A

[5] EEVC (1982): Pedestrian Injury Accidents. Proc. of the 9th Int. Tech. Conf. on Experimental Safety Vehicles, Kyoto, Japan. Nov. 1-4, 1982. US Dept. of Transportation, NHTSA, USA. pp. 638-671

[6] NHTSA (1993): Pedestrian injury reduction research, Report, National Highway Traffic Safety Administration, US Dept. of Transportation, Washington DC, U.S.A

[7] D. OTTE, C. KRETTEK, H. BRUNNER, H. ZWIPP (2003): Scientific Approach and Methodology of a New In-Depth-Investigation Study in Germany so called GIDAS, Proceedings of the 18th ESV Conference, Nagoya, Japan, Paper No. 161

[8] D. OTTE (1999): Severity and Mechanism of Head Impacts in Car to Pedestrian Accidents, Proceedings of International IRCOBI Conference on Biomechanics Impacts, Barcelona, Spain, pp. 329-341

[9] D. OTTE, T. POHLEMANNN (2001): Analysis and Load Assessment of Secondary Impact to Adult Pedestrians after Car Collisions on Roads, Proceedings of the International IRCOBI Conference on the Biomechanics of Impacts, Isle of Man, United Kingdom, pp. 143-157

[10] Y. MIZUNO, H. ISHIKAWA (2001): Summary of IHRA Pedestrian Safety WG Activities-Proposed Test Methods to Evaluate Pedestrian Protection Afforded by Passenger Cars. The 17th ESV Conference, June 4-7, 2001, Amsterdam, The Netherlands

[11] M. DANNER, K. LANGWIEDER, W. WACHTER: Injuries to Pedestrians in Real Accidents and Their Relation to Collision and Car Characteristics. Department of Automotive Engineering Association of German Automobile Insureranse

[12] L. Li, J.K. Yang, W.Q. Li, H.F. FANG: A Study of Pedestrian Injuries in Traffic Accidents in Changsha of China. Journal of Hunan University. 2002. Vol. 29:15-23

[13] NHTSA (1999): Traffic safety facts – pedestrian, Report, National Highway Traffic Safety Administration, Department of Transportation, Washington DC, U.S.A.

[14] EEVC (1994): Proposals for Methods to Evaluate Pedestrian Protection for Passenger Cars. Report, European Experimental Vehicle Committee, working group 10

[15] ETSC (1997): A Strategic Road Safety Plan for the European Union. European Transport Safety Council, Brussels

A. Tenzer
Volkswagen AG, Group accident research,
Wolfsburg, Germany

W. Hongyan
Tongji University, Department of Automotive,
Shanghai, PR China

In-Depth-Study in JiaDing District, Shanghai Considering as an Example for Accident Research in the Peoples Republic of China

1 Abstract

76 severe traffic accidents had been investigated in depth in an ongoing Volkswagen-Tongji University joint accident research project in JiaDing district, Shanghai, PR China since June 2005. With a methodology similar to German accident research units in Dresden and Hannover, a research team proceeds to the scene immediately after the incident to investigate and collect various data on environment, accident occurrence, vehicle state and deformations as well as injuries. The data combined with the results of accident reconstruction will be stored in a database for further statistical and casuistic analysis. The first outcome of the project supports the hypothesis that a main causation for the large number of traffic accidents in China is the lacking of risk awareness in Chinese driver behaviour. Low seat-belt use and the high proportion of vulnerable and poorly protected two-wheelers in traffic are reasons for the high injury and fatality rate in China. The research work shows that accident research in China is feasible and able to give support to tackle one of the urging problems in Chinese development.

2 Motivation/Why Accident Research in China

China has one of the most developing economies in the world. The average annual GDP growth from 1994 to 2004 is 8.3%.[1] This economic growth leads to an increase in mobility and as a side effect also to an increase in traffic accidents (Figure 1).

Comparred to other developed countries in Figure 2 China is far behind in the number of vehicles and in the ratio vehicle per inhabitant but ahead in the number of fatalities and in the ratio fatalities per 1,000 vehicles. With the ongoing economical success in China and the combined increase of vehicles, there is little space for hope that a general change in the trend of accident figures occurs without establishing countermeasures. This joint research project will help to define countermeasures by analysing Chinese road traffic accidents in depth. The goal of this project is to get a deep understanding of traffic accidents in China and to identify the effects on traffic safety to ensure a sustainable mobility. Therefore it is necessary to

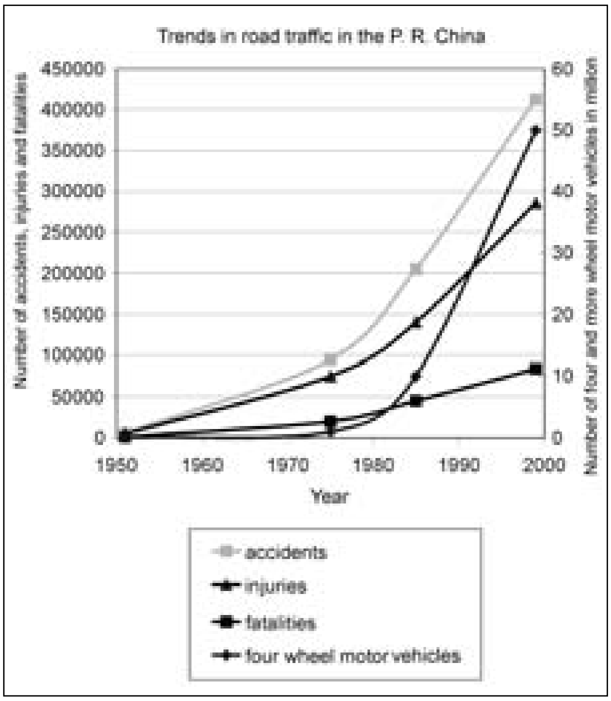


Figure 1: Development of fleet and accident figures in China

	USA	PR China	15 EU Countries	Germany
Population (Mio.)	293	1.298	380	82
Area (Mio. km^2)	9,1	9,6	3,2	0,36
Fleet (Mio. passenger cars)	130	ca. 13	186	44
Fatalities (1000)	42,8	ca. 105	37,3	6,6 (2004: 5.85)
Passenger cars 1000 inhabitants	443	ca. 10	488	538
Length of road net (Mio. km)	6,4	1,4	3,8	0,23
Fatalities per 1000 vehicles	0,33	8,1	0,20	0,15 (2004: 0,13)
Data from	2002	2003	2001-2003	2003

Figure 2: A comparison of traffic and accident related figures[2]

1 http://www.worldbank.org.cn/English/Content/chn_aag02.pdf

2 Data from: IRTAD, CIA World-Fact-Book, Eurostat, Stat. BA, China Internet Information Center

investigate the accident situation in this country in depth both statistically and in case studies.

3 The Volkswagen-Tongji University Joint Research Project

The Volkswagen-Tongji University joint research project started in May 2005 under executive of the professorship of Body Structure Design and Passive Safety at Tongji University by initially forming a research team which consists of 10 students of automotive department and one team leader. The training is conducted by scientists from Volkswagen group accident research which also formed the advisory board. Training procedure includes investigation of accident scene, investigation of vehicles, accident reconstruction and accident data processing. A holistic approach to accidents should lead the research team to see an accident not only as an accumulation of data but to gain a fully understanding of the accident from the situation the driving process becomes critical to the identification of impact points inside and outside the vehicle and their related injuries. Finally the team members are not only able to collect data but also gain understanding of traffic safety and accident causation.

Figure 3: Accident research vehicle of joint research

The research area is at first restricted to JiaDing district, an area of 458.8 km^2 with a population of 474,100 (as of 2001).[3] JiaDing district covers urban as well as rural area with also industrial area and farm land. The surface is plain and its altitude is close to sea level. The distribution of different road types can be seen in Figure 4.

Shanghai traffic police authorities were involved in the project at a very early stage which results in a

3 http://en.wikipedia.org/wiki/Jiading

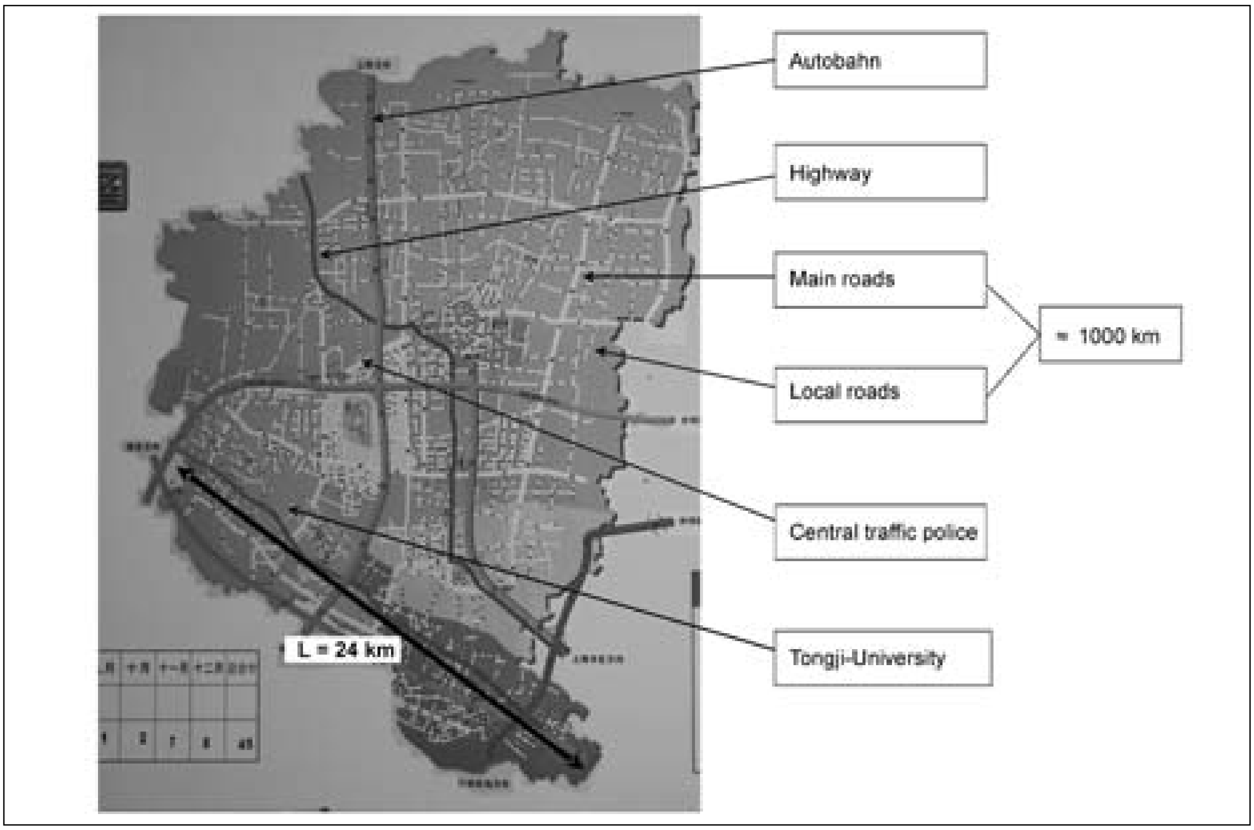


Figure 4: JiaDing District Shanghai

good acceptance and relationship. Beneficial for the project is that both Shanghai central traffic police and JiaDing traffic police support the research work to a large extend.

4 Methodology

The accident investigation is conducted in order of the subsequently listed steps:

1. Informed by police, the research team members proceed immediately to the accident scene. A full investigation of the scene including measurement and photographing of final positions, marks and the surrounding of the spot is accomplished.
2. Investigation of all involved vehicles on scene or later including general vehicle data, deformations, impact points inside and outside the vehicles and marks indicating the movement of passengers and/or pedestrians/cyclists. Also the state and usage of restraint systems or protection devices like helmets will be recorded.
3. Documentation of accident related injuries as well as blood-alcohol concentration or drug use. Further personal related data as age, gender, age of driving license or education are collected.
4. Accident reconstruction to gain information on impact speed, direction and momentum of impact and loss of velocity. A time-path analysis figures out closing speed, distance and time between point of reaction to point of impact and accident avoidance.
5. Internal discussion on every accident to get a full comprehension of accident causes, outcome, mitigation and avoidance possibilities according to a holistic approach
6. Data proceeding. Similar to the data scheme of GIDAS[4], the accident data will be filed in a database for further statistical analysis.

5 First Outcome

From June 2005 to June 2006 76 accidents had been recorded and investigated in depth. 50 (65.7%) of them are accidents with at least one injured person and 9 (11.8%) of them are fatal. 33 (43.4%) cases from the overall sample are accidents involving trucks or busses and 23 (30.2%) are accidents with two-wheelers. The recorded number of pedestrian accidents is with 2 (2.6%)

4 German In-Depth Accident Study; www.gidas.org

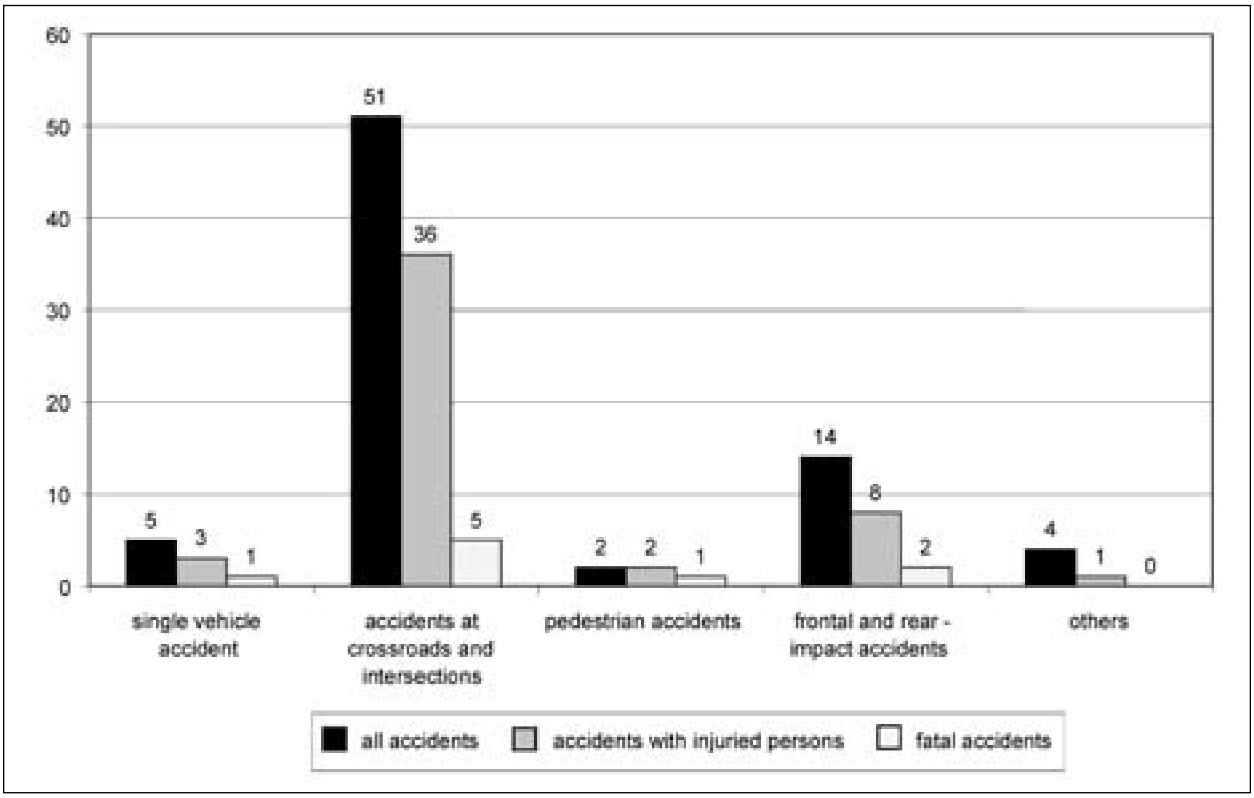


Figure 5: Accident type distribution

comparably small. Figure 5 displays the distribution of type of accidents within the sample. Besides of the fact that the number of accidents is not statistically representative, yet, some basic conclusions on accidents in China concerning causation and injury risk can already be derived from the data.

A hypothesis for Chinese biggest problem concerning traffic safety is the lack of risk awareness.[5] One possible reason for this problem can be a missing "automotive socialisation". In developed countries people obtain their driving license after a long period of automotive socialisation. They grew up with high traffic density and they are used to drive with their parents from early childhood days, they are familiar with traffic when they enter driving school. China's enormous economical growth changes society from a "kingdom of cyclists" to modern traffic within less than 20 years. It is presumed that the development of individual risk awareness could not keep pace with development of traffic. People in their middle ages now become wealthy enough to afford their first own vehicle but didn't have much experience in traffic. This hypothesis is supported by three findings:

Accidents on crossroads

51 accidents (67.1%) of all accidents in the sample occurred at intersections and 39 (51.3%) of all accidents are represented by only three different types, impact to a vehicle coming from left which represents 17 cases (22.4%), impact to a vehicle coming from right (14 cases i.e. 18.4%) and heading into oncoming vehicles when turning left (8 case i.e. 10.5%). China has appropriate traffic rules[6] and crossroads in JiaDing district are often spacious and major crossroads are usually equipped with traffic lights. Main causes for the above mentioned accidents are violating of right of way and misinterpreting the time gap between two oncoming vehicles in a case of making a left turn. Violating the right of way refers basically to a lack of risk awareness. The false estimation of speed and distance of oncoming vehicles is – if not an enforcement of right of way – primarily a problem of being short on experience. A case study will illustrate the above mentioned:

A Santana was hit at nighttimes by a DongFeng truck on a crossroad shown in Figure 6. Impact speed of the truck was 69 km/h while the Santana was travelling at 80 km/h. The truck driver claims

Figure 6: Accident scene Santana vs. truck

Figure 7: Lateral impact of Santana by truck

[5] cp. ZHANG, W. et al.: Driver's view and behaviors about safety in China – What do they NOT know about driving. In: Accident analysis and prevention, 2006 38 (1) 22-7

[6] http://english.gov.cn/laws/2005-09/07/content_29966.htm Article 38;44

that he had the priority when entering the crossroad. Due to a severe head trauma, the driver of the Santana was not able to give a statement. The traffic lights are working, both vehicles used headlights and there was no limitation of visibility besides darkness. It can be stated that one of the participants violated the way of right by running over red light. The high impact speed of both vehicles indicates that none of the drivers had been aware of the risk at crossroads, neither the driver who had the right of way nor his opponent, violating it.

Poor seat-belt usage

The usage of seat-belts in combination with rigid driver compartment is life-saver number one in car accidents.[7] The sample of 76 cases includes 86 passenger cars and delivery vans. In 36 of the cars the had been clear indications for not wearing a seat-belt for any of the passengers. This is a belt wearing ratio of 58.1%. It has to be stated clearly, that this could be an overestimation, because even at accidents with a minor crash pulse (e.g. car vs. two-wheeler) indicators for seat-belt use as belt marks can hardly be found.

A case study: A Volkswagen Polo with five passengers was going along an autobahn when caused by driver distraction the car suddenly turned right and had a frontal impact to the guard-rail at a speed of approx. 40km/h. The guard-rail collapsed and the car fell down a four meter slope and had a second impact on the ground with the rear end. All passengers had been unbelted and were severely injured. A young woman aged 25 was ejected from the co-driver's seat through the closed hatch window and remains paralyzed. The paralysis was caused by a vertebral fracture. As can be seen in Figure 8 there is no deformation in the driver compartment. so it can clearly be stated that this accident only would have caused minor injuries if all passenger did buckle up.

7 ZOBEL, R.: The safety effect of active and passive systems, ITS World Congress, San Francisco, 2005-11-0

Risk of two-wheelers

Cases with bicycle and motor-cycle involvement are 30.3% of all investigated accidents which is a comparably high figure to developed countries. According to Figure 9 the probability of injuries rises by involvement of two-wheelers from 11.8% to 21.7% (fatalities from 65.8% to 95.7%). All accidents analysed so far within this project, the opponent, i.e. the passengers of car or truck, remains unharmed. This leads to the conclusion that cyclists show a high vulnerability. This is supported by the fact that in all recorded accidents, none of the motorcyclists had worn a helmet. Helmets for bicyclists are nearely unknown in China.

From all 23 cases with involvement of two-wheelers, 19 (82.6%) cases occurred on crossroads. One possible outcome of further accident research within this project can be that a separation of bicycles and small motorcycles from all other vehicles and safe crossing possibilities will have an impact on these figures.

Besides, cyclists should also train their personal risk awareness. As shown in Figure 10, a 42% decrease in the number of accidents can be found when day changes to nighttime. By contrast accidents with two-wheelers decrease only by 8%. Proper lighting can be the key so lighting of bicycles and retro-reflective devices are widely unknown and even motorcycles drive sometimes without light at nighttimes.

Figure 8: Accident scene (with refurbished guard-rail) and VW Polo

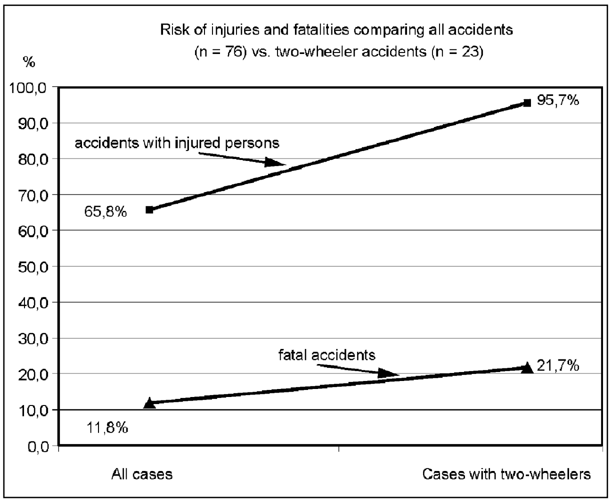


Figure 9: Increase of risk for driver of two-wheelers

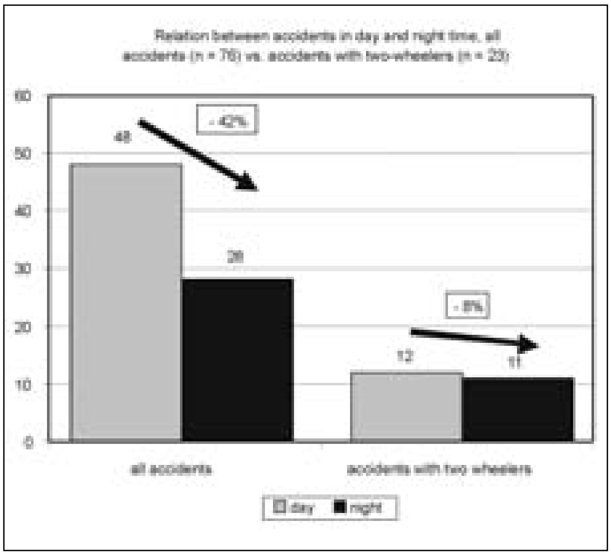


Figure 10: Increase of risk in nighttimes

Once again it should be mentioned that these findings are based on 76 investigated accidents in Shanghai and they are not statistically representative for China in general, but they point out first conclusions.

6. Conclusions and Next Steps

It can be noticed after nearly one year of accident research in JiaDing district that in-depth accident research in China is feasible and achieves reasonable results giving a first insight into Chinese problems in traffic safety. Together with Chinese authorities and the scientific community in China research partners and stakeholders came to the conclusion that it will be beneficial for China to further carry on with accident research. Besides of the positive results, there are some further actions to take to intensify the research work and getting a wider view on accidents in China. These steps are mainly:

- widen the area of accident investigation to cover all Shanghai districts,
- improve the medical data collection,
- prove the statistical representativeness of the accident data,
- further data collecting.

W. Klanner, T. Unger
ADAC Technical Centre, Germany

Concept and First Results of the ADAC Accident Eesearch Based on the Data of ADAC Air Rescue Stations

Abstract

The fact that ADAC Air Rescue handles approximately 4,000 road accident missions every year gave rise to set up an accident research programme for which ADAC Air Rescue provides its data. This data is of initial informational quality and will be supplemented by data from the police, experts, fire brigades as well as hospitals and forensic institutes.

Although the number of cases is still rather low, certain tendencies can be identified. The causes for most accidents occur when joining or intersecting traffic, followed by speeding in road bends and tailgating. Many accidents involve HGV rear end collisions, often causing serious injuries, considerable damage and technical problems for the rescue operations. With regard to the various impact types, it has become obvious that most of the extremely serious injuries are inflicted during a passenger car side impact.

In addition, access to and removal of trapped passengers is becoming more and more complicated, partly due to the increasing use of high-strength materials, and rescue operations tend to be more time consuming.

Introduction

ADAC's history in air rescue goes back more than 30 years. Since an average of 10% of 40,000 missions per year are related to road accidents, the idea was to set up an accident research programme based on our collected data.

The project objectives were defined as follows:

- Discovery of accident and injury causes.
- Further development of on-going consumer protection test projects using real accident data.
- Development of new crash test procedures.
- Identification and solution of technical problems in passenger rescue.
- Correlation of in-hospital and pre-hospital diagnosis.
- Support to improve onsite diagnosis.
- Annual report on ADAC accident research conclusions.

Within the framework of a one-year pilot project, the research team was to define and test the required methods to achieve the above targets. The identified method relies on the initial information from ADAC Air Rescue on registered accidents. This is enhanced with data supplied from the police, experts, fire brigades and hospitals and forensic institutes.

The pilot project has been concluded. It was found that the set objectives can actually be achieved using the developed method. The project findings may contribute to further improve road safety.

First results of the ADAC accident research programme

ADAC Air Rescue took care of patients during 33,940 missions in 2005. The illustration in shows the mission spectrum with 14% involving road accidents (Figure 1).

More than half of the road injuries involve car or HGV passengers, 26% are motorcyclists, 11% cyclists and 5% pedestrians (Figure 2).

To identify the most frequent injuries among the accident victims, we referred to the anonymous emergency physicians' protocols from the ADAC

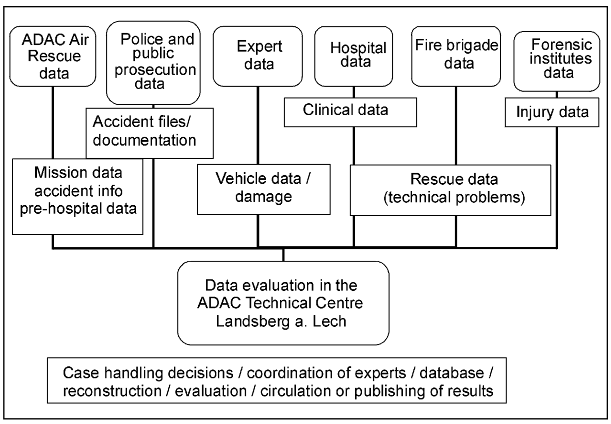


Figure 1: Data sources of the ADAC Accident Research

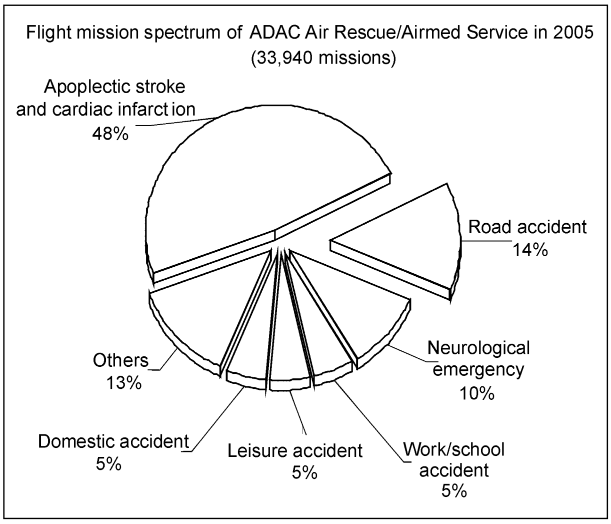


Figure 2: Flight mission spectrum in 2005

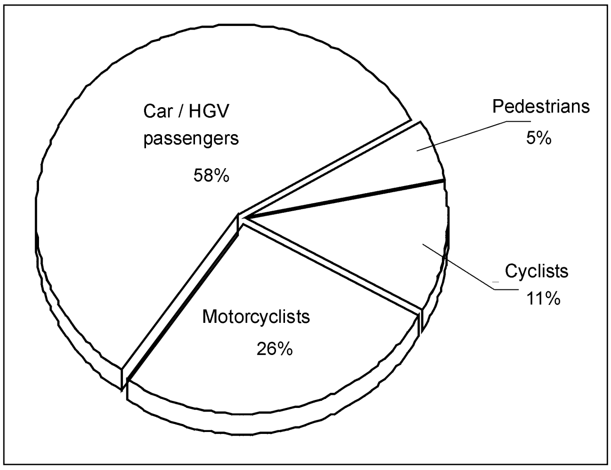


Figure 3: Persons involved in road accidents registered by the ADAC air rescue teams

helicopter crews. The column diagram shows the distribution of the most serious, i.e. life-threatening, and fatal injuries among the individual body parts. The results are plotted for the different groups involved in an accident, i.e. car and HGV passengers, motorcyclists, cyclists and pedestrians.

100% is the total occurrence of the most serious injuries to the individual body areas.

Head injuries are most common in all accident victims. The most frequent and dreaded kind of injury is the serious craniocerebral injury which mostly affects cyclists with a 70% rate. This is a clear indication of how significant it is to wear a helmet when riding a bike.

Pedestrians are also very prone to head injuries when involved in an accident. This supports

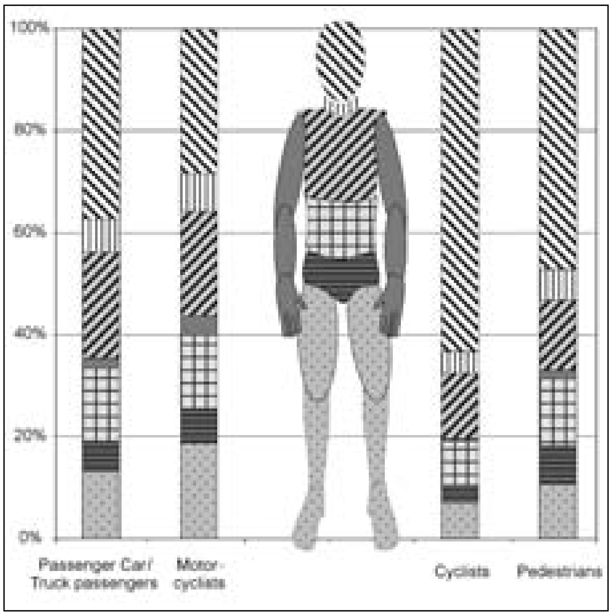


Figure 4: Fatal or life threatening injuries by involved person groups

ADAC's demand for remodelling potential impact zones in the bonnet area to minimise the aggressiveness of vehicle front areas.

Chest injuries range second among the most serious injuries and in most cases imply broken ribs and associated serious lung injuries.

To the exception of motorcyclists, abdomen injuries, mostly affecting the inner organs and involving dangerous internal bleeding, come third.

The third most frequent injury type for motorcyclists are leg injuries. For the other groups these take fourth position. Usually, severest fractures and dangerous complications are involved. Since such injuries often entail extremely long he4ling processes, they must be taken into account in safety developments.

When comparing the data of all ADAC Air Rescue missions in Germany (2005) with the data stemming from only two bases, the random test results are shown to deliver a highly reliable picture of the typical situation in Germany. The selected air rescue bases collect additional important data on road accidents allowing for a more profound analysis of each case. Almost all accident victims recorded at the bases in question have suffered serious injuries (87.5%). Therefore, air rescue data does not provide a complete picture since they primarily relates to severest accidents, whereas the range of general accidents is not covered.

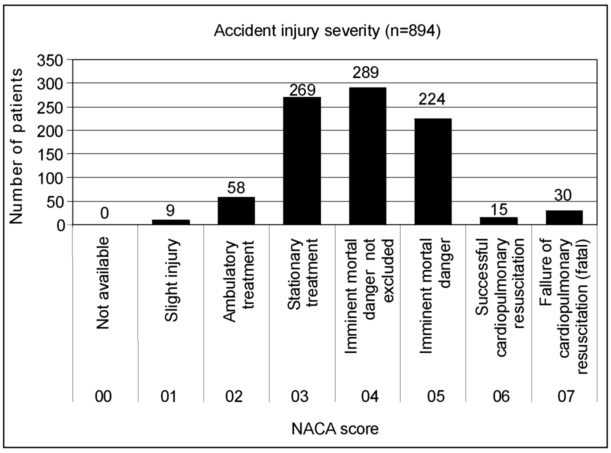


Figure 5: Distribution of the NACA score

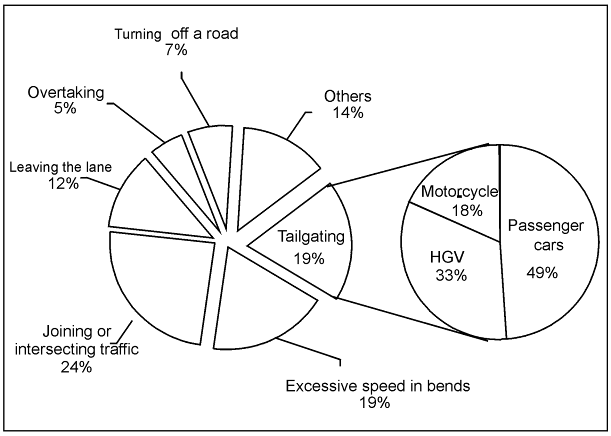


Figure 6: The most frequent accident causes

Figure 5 shows the distribution of the injury severity (NACA score).

The injury severity aspect underlines the immediate necessity to avoid the most serious accidents. We therefore analysed the causes of the accidents and their most important factors referring also to the pertaining data from the police. The analysis revealed again that the accidents are usually caused by human failure.

In most cases, the following three errors account for the most serious road accidents:

1. Error when joining or intersecting traffic.
2. Failure to maintain distance/rear end collision.
3. Speeding in bends.

When joining or intersecting traffic, motorists also make mistakes at crossings with an expressway having right of way and which have good visibility. In these cases the errors can often be ascribed to the wrong assessment of the speed of the vehicle having the right of way.

Future joining/intersecting traffic assistance systems should help drivers to avoid such errors and consequently serious accidents, or at least attenuate them. Systems of the kind are not yet available on the market, but they would certainly account for much safer roads just as ESP does today.

Suitable support systems against errors regarding the safe distance between vehicles/tailgating are already available for some vehicles of the superior class, e.g. the so-called brake assistant plus (BAS+) in the Mercedes S class. Equipping also other vehicles with a comparable system would be a decisive step towards counteracting this error.

It is striking that in rear-end collisions HGV are to a very large extent responsible for the accident. Random tests revealed that on motorways approximately 30% of such accidents involve HGVs. Often, very serious injuries, substantial material damage and technical rescue problems are the consequence. In view of such appalling effects, ADAC calls for the introduction of the emergency brake assistant in commercial vehicles. We are convinced that this type of safety system can reduce rear-end collisions, both involving HGV and HGV or HGV and passenger cars. In either case, accidents are mostly of disastrous proportions.

The widely used driving assistance system ESP has effectively contributed to bring down accident probability caused by excessive speeding in curves. Equipping all new vehicles with ESP will help to reinforce the tendency of reducing this type of accidents.

With regard to the various impact types reported in accidents involving passenger cars, the percentage (relative to the respective case figures) of very seriously/fatally injured passengers is higher in a side crash than in a front crash irrespective of the age of the car.

This tendency would contradict today’s EuroNCAP results which maintain that usually more points are scored in a side crash than in a front crash (i.e. greater safety in a side crash). Consequently, side crash test procedures would have to be intensified. However, this requires verification by means of looking in more detail at a larger number of accidents.

Head, thorax and abdomen are the most frequently injured body areas in passenger car side impacts and are already covered in the EuroNCAP assessment procedure for side crashes. Looking at and evaluating pole crash tests at the same time could also help to improve passenger safety in the case of side impacts.

The side-impact pole test is ideal for an assessment of the structural rigidity of doors, side panels, columns and door sills as well as of the interior and airbag systems. In addition to the local load transmission and the very fast intrusion,

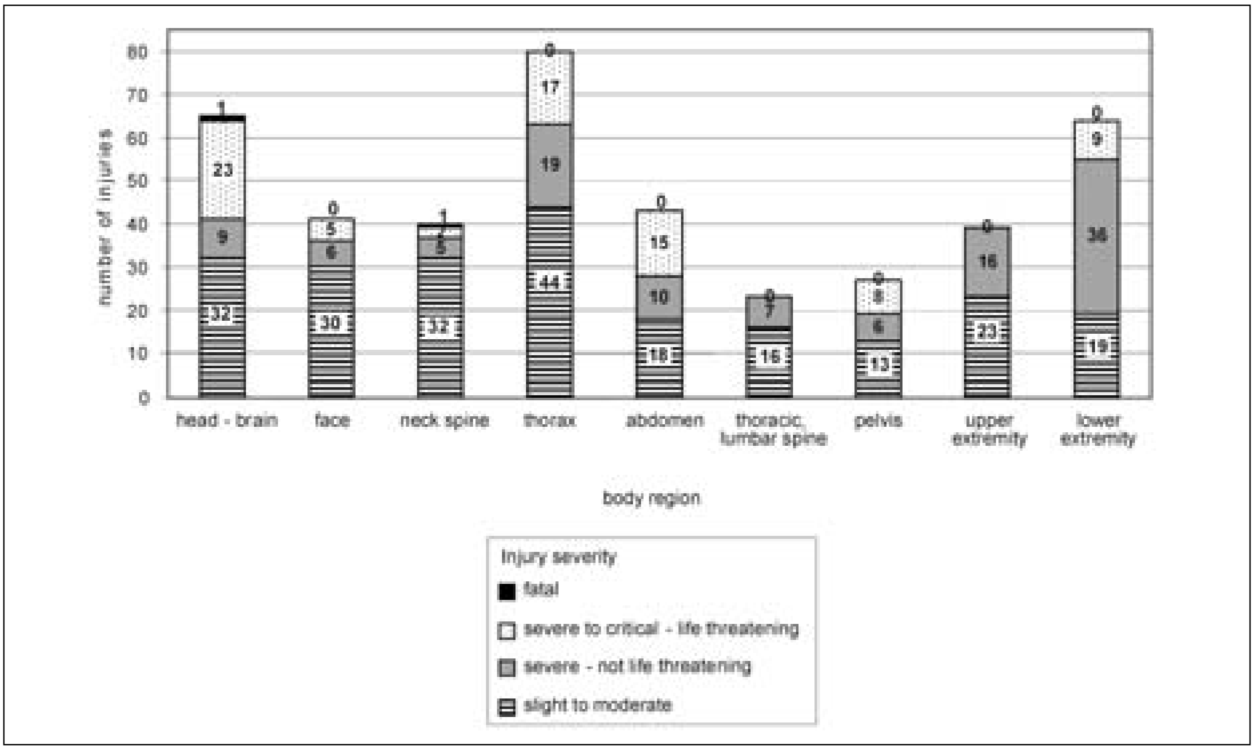


Figure 7: Injury pattern of passengers – frontal collision (n=150)

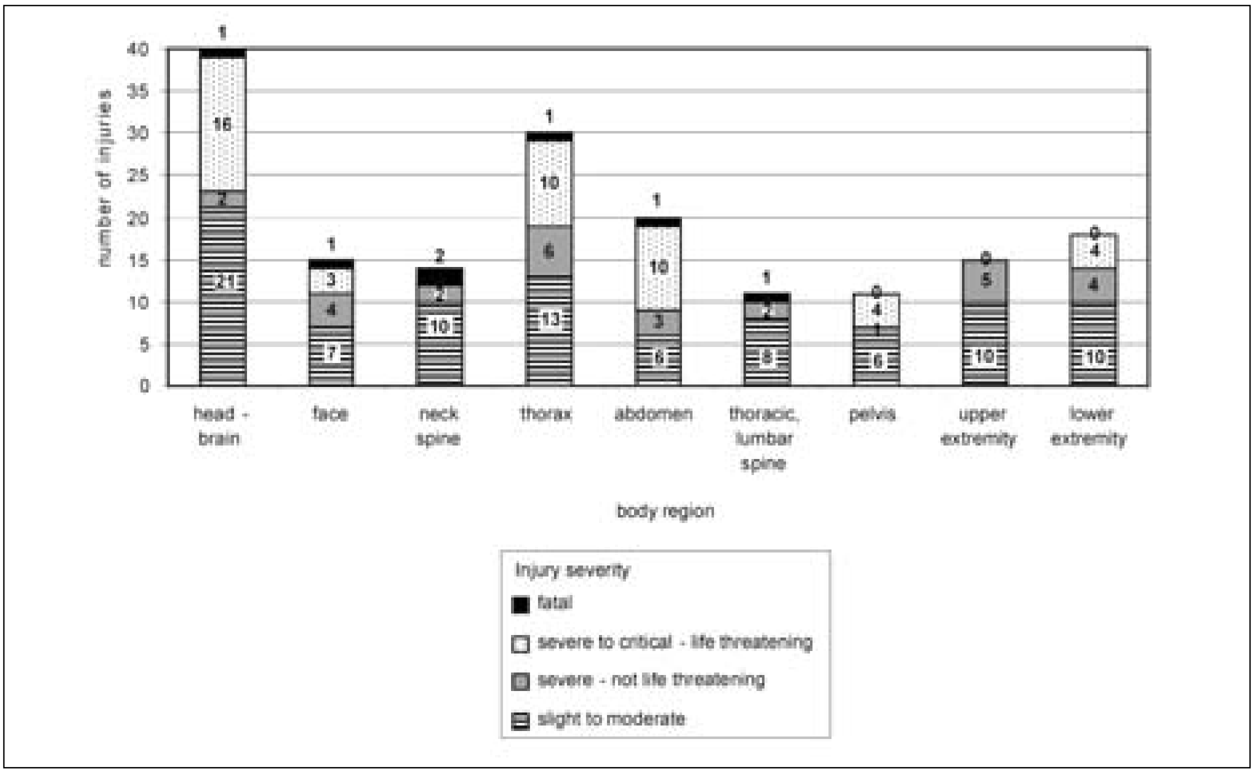


Figure 8: Injury pattern of passengers – side collision (n=63)

the structures and safety systems are given by the acid test. The support functions of A and C columns no longer have an effect, only the perfect interaction of structure and safety equipment is able to achieve a good result.

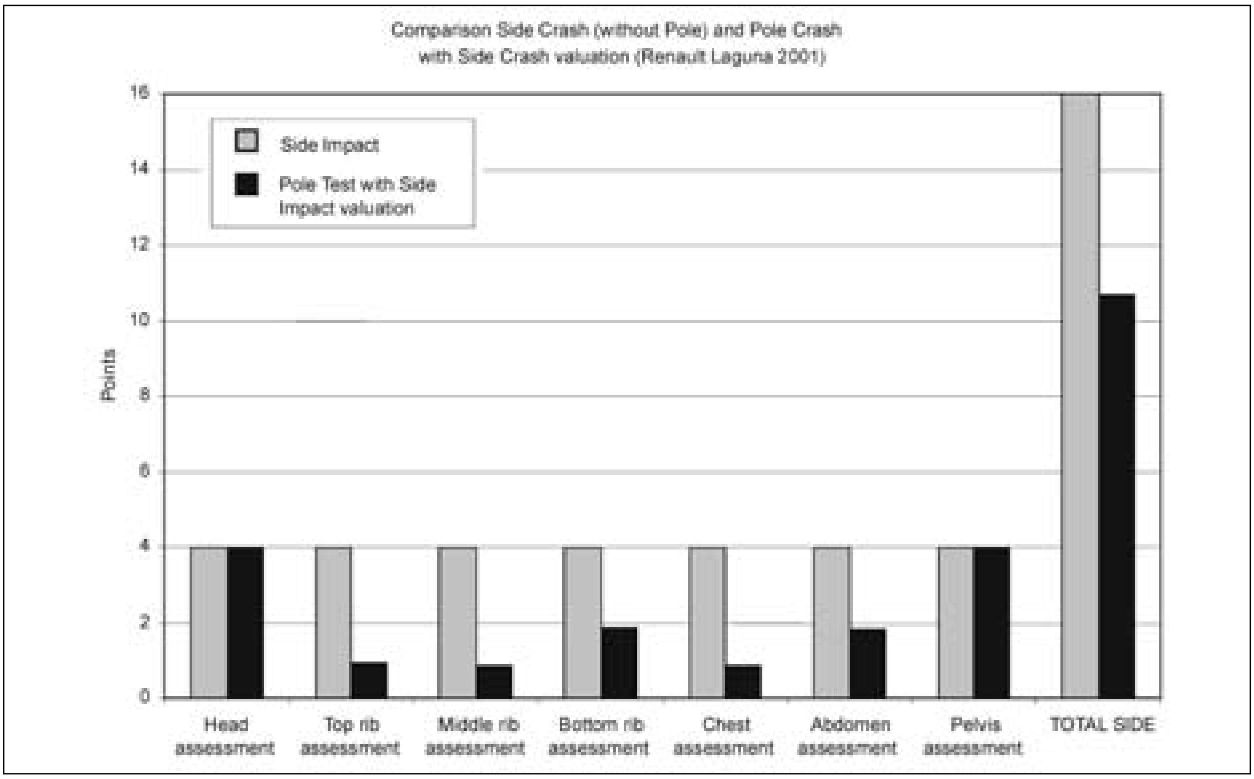


Figure 9: Comparison of side performance – Renault Laguna 2001

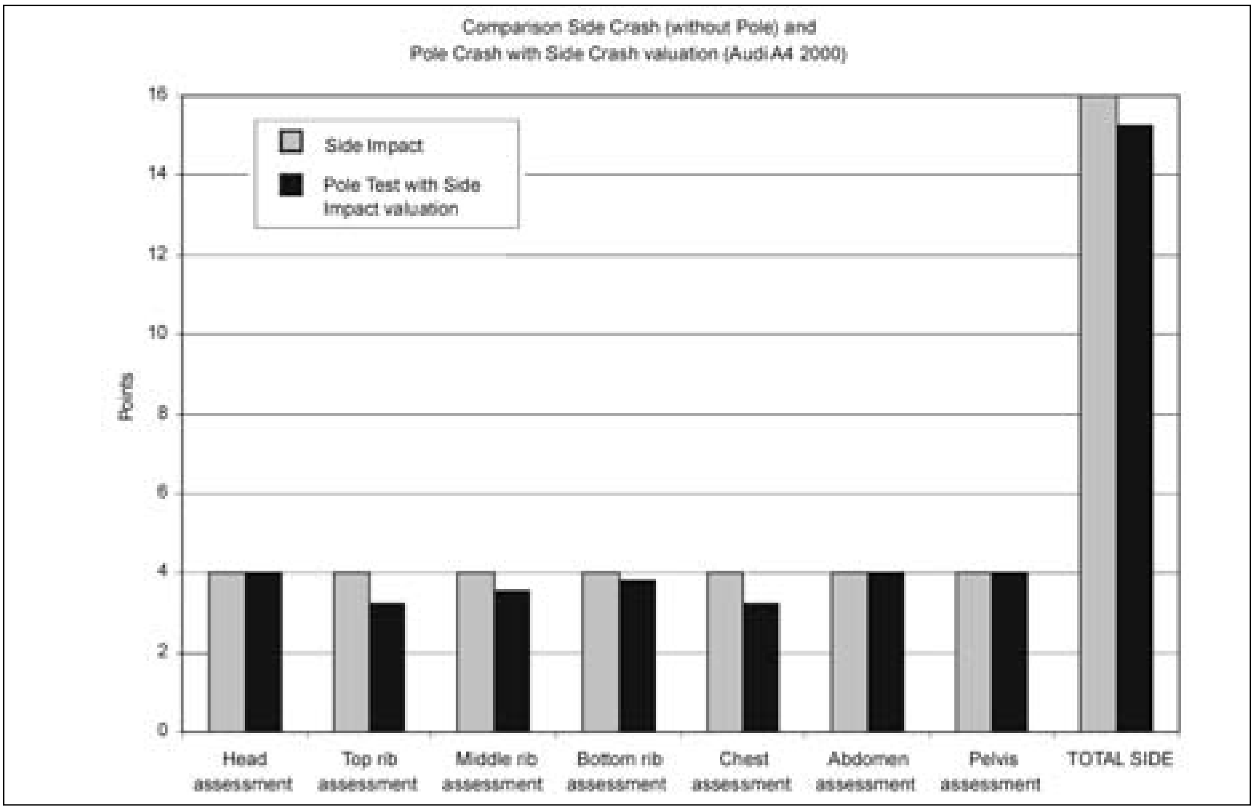


Figure 10: Comparison of side performance – Audi A4 2000

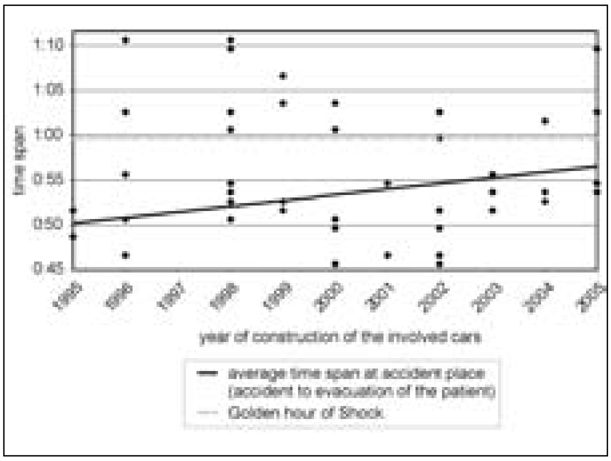


Figure 11: Average time at the accident place – accidents with technical rescue actions

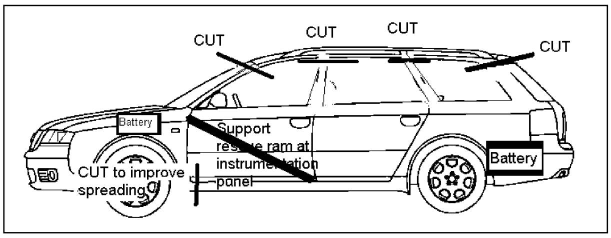


Figure 12: Proposal of a "escue label"

We selected several cars, which were tested in the same laboratory at equal test conditions and according to the official EuroNCAP procedure, to illustrate how differently vehicles of the same class behave during pole testing. The models under review have already been tested in 2000 and 2001.

Pole test results were transferred to the EuroNCAP assessment scheme for side impacts and converted into points in order to compare them with the achieved number of points of side impacts as can be seen in Figure 9 and 10.

It is very evident that the side impact behaviour of individual vehicles can produce very different results even if they were tested under the same conditions. The structural rigidity which is vital during impact considerably affects the injury risk of passengers. The comparison reveals the great potential inherent in the side structures. Further development in this area would advance side crash performance.

The rescue of passengers trapped in today's vehicle models increasingly causes technical problems. The use of high-strength materials challenges the technical equipment of fire brigades. The use of more than one battery in different places may also account for difficulties during rescue. Speedy and optimal discovery of suitable cutting positions at the roof edges for the removal of the roof often proves extremely difficult, because the airbag gas generators cannot be detected easily and the columns may have been reinforced and are very stiff. Naturally, more time is required for the rescue and the transfer of traumatised patients to the hospital is often delayed. A first analysis confirmed the tendency that the period of time between the accident and the patients' transfer to a hospital is growing depending on the crashed vehicle's year of manufacture. In the framework of this study, accidents were evaluated which required technical rescue equipment. Relevant data are currently being collected to verify the described tendency.

The tendency to exceed the defined pre-hospital time ("golden hour of shock") is alarming. The 60-minute pre-hospital time limit is a recommendation to improve survival of traumatised patients.

To counteract these problems, a rescue label could be developed. This label could be introduced to provide the most essential on-site information for rescue requiring technical equipment (max. 4-5 details) and top all other rescue guidelines which are already available but which tend to be rather voluminous. By attaching the label to the vehicle, the most essential details would be available in the quickest, securest and most relevant manner.

Conclusion

First results of the ADAC accident research pilot project underline the efficiency of this new ADAC programme. In addition to individual assistance in an emergency, ADAC Air Rescue also serves the public well by contributing to the improvement of road safety.

Further to the pilot project, the ADAC accident research will continue its programme. The pilot project was limited to only 2 air rescue bases, those in Ulm and Munich. Since November 2005, research has continually been expanded to include all ADAC Air Rescue bases to cover a higher number of cases and achieve more validated results. At the moment, between 1,500 and 2,000 cases per year can be evaluated.

The tendencies already perceivable will now be further analysed and evaluated. The follow-on project will focus on a number of key issues such as the in-depth study of side impacts, the development of a “rescue label” and the correlation of pre-hospital and in-hospital data.

Further future issues concern the safety of children and motorcycle accidents as well as the provision of a profound analysis of accident causes, so that the improvement of road safety can be further promoted.

J. Lenard, A. Morris, J. Barnes
VSRC Loughborough University, UK
E. Tomasch
Technical University of Graz, Austria
J. Nehmzow, D. Otte
Medical University of Hannover, Germany
L. Cant, M. Haddak, G. Vallet
INRETS, Lyon, France
H. Ebbinger
Chalmers University, Gothenburg, Sweden
Y. de Vries
TNO, Delft, The Netherlands
B. van Kampen
SWOV, The Hague, The Netherlands
J. Paez
INSIA-UPM, Madrid, Spain

PENDANT: A European Crash Injury Database

Abstract

Annually within the European Union, there are over 50,000 road accident fatalities and 2 million other casualties, of which the majority are either the occupants of cars or other road users in collision with a car. The European Commission now has competency for vehicle-based injury countermeasures through the Whole Vehicle Type Approval system. As a result, the Commission has recognised that casualty reduction strategies must be based on a full understanding of the real-world need under European conditions and that the effectiveness of vehicle countermeasures must be properly evaluated.

The PENDANT study commenced in January 2003 in order to explore the possibility of developing a co-ordinated set of targeted, in-depth crash data resources to support European Union vehicle and road safety policy. Three main work activity areas (Work Packages) commenced to provide these resources. This paper describes some of the outcomes of Work Package 2 (WP2, In-depth Crash Investigations and Data Analysis).

In WP2, some 1,100 investigations of crashes involving injured car occupants were conducted in eight EU countries to a common protocol based on that developed in the STAIRS programme. This paper describes the purposes, methodology and results of WP2. It is expected that the results will be used as a co-ordinated system to inform European vehicle safety policy in a systematic, integrated manner. Furthermore, the results of the data analyses will be exploited further to provide new directions to develop injury countermeasures and regulations.

1 Introduction

Annually within the European Union, there are over 50,000 road accident fatalities and 2 million other casualties. The majority of these are either the occupants of cars or other road users in collision with a car. Through the Maastricht Treaty the European Commission now has competency for vehicle-based countermeasures through the Whole Vehicle Type Approval system. Casualty reduction strategies must be based on a full understanding of the real-world need under European conditions and their effectiveness must be properly evaluated. There is however no co-ordinated mechanism available to the Commission to provide a suitable resource with which to support new safety actions and to provide feedback. A major gap concerns the availability of pan-European data on injuries and their causation for qualitative and quantitative support for European policy.

As described in the STAIRS project [1], a single European-wide crash injury database would be of exceptional benefit to the legislative process at EU level. A direct data-driven approach would allow identification of any safety problems at an early stage and would facilitate quick and accurate evaluation of new technologies and remedial measures, including legislation, that may have been implemented. The overall aim of the STAIRS project was to take the first steps towards this goal. The project involved standardisation of in-depth road accident data collection methodologies which would provide the core framework for any pan-European crash injury studies. This included specification of a number of key data variables, case selection criteria and general investigative approach.

At the conclusion of the STAIRS project, the EC stated that there was general support in principle for the implementation of its recommendations, albeit with certain barriers that needed to be overcome. There was a suggestion that the EC's 5th Framework programme could incorporate an additional stage beyond STAIRS whereby the basic building blocks of STAIRS could be implemented on a limited basis. This would include validation of the main recommendations, an assessment of its usefulness and determination of its limitations. This set the scene for the development of a major element of work which became Work Package 2 of the PENDANT (Pan-European Co-ordinated Accident and Injury Databases) project.

The aim of Work Package 2 was to bring together the resources and infrastructures of existing accident and injury investigation groups to build a demonstration European crash injury database. It was the intention that the database could be continued and enhanced after the completion of this project to become a central European resource which would facilitate road and vehicle safety decisions and policy making. It was also the intention that the database would be used to examine the injury prevention priorities for future action and to provide feedback to European casualty reduction measures such as the EuroNCAP rating system.

Following the final development of the standardised demonstration database system to facilitate data entry and combined analysis, further objectives of PENDANT Work Package 2 included (a) to investigate at least 1,100 accidents involving injured car occupants or pedestrians and compile the data into the database, and (b) to analyse the composite database and identify priorities for future European regulatory and other action. The methodology of PENDANT data collection, sample results from analysis of the database, and priorities identified for future action are described in the following sections of this paper.

2 Methodology

At the outset of the PENDANT study, the EC comprised 15 member states. Groups from 8 of these countries participated in in-depth crash injury data collection, with sample areas in northern, central and southern Europe to give a range of accident conditions that was as representative as possible. These organisations were Technical University of Graz (Austria), University of Turku/VALT (Finland), INRETS, CETE-SO and ARVAC (France), Medical University of Hannover (Germany), TNO and SWOV (the Netherlands), UPM-INSIA (Spain), Chalmers University (Sweden) and Loughborough University (UK).

The basic data collection protocol, including the specification of the core data to be gathered, was developed within the earlier STAIRS project that was completed in March 1999. It mainly relates to passive safety. This protocol was developed into appropriate data collection forms that were updated to take into account technology developments. Some additional fields were included to provide an overview of accident causation events, although not in great detail, as this was not the main purpose of the project.

It was intended that a special feature of the data would be the case selection methodology which would be targeted on newer vehicles to efficiently provide data that has value for regulation and safety countermeasures. The accident selection criteria for inclusion in the database were accordingly set as follows:

- M1 and N1 Passenger vehicles manufactured on or after 1st January 1998 involved in crashes with other passenger vehicles (providing that injury occurred in either vehicle).
- M1 and N1 Passenger vehicles manufactured on or after 1st January 1998 involved in crashes with other non M1/N1 vehicles (e.g. trucks/buses) providing injury occurred to at least one occupant of the passenger vehicle.
- M1 and N1 Passenger vehicles manufactured on or after 1st January 1998 involved in single-vehicle crashes (e.g. pole, tree, and rollover).
- 20% of accidents from each data collection centre to be of MAIS 3+ injury severity. The remaining accidents to be sampled randomly from the geographical regions in which teams operate.
- A maximum of 10% of the required case-load for each partner could comprise pedestrian crashes.

In general, all teams adopted similar data collection procedures although some differences were apparent. The main system of crash notification was via the police. Some teams investigated accidents immediately on receipt of notification whilst other teams investigated cases in the days after the crash. The sample regions may be broadly characterised as Graz region (Austria), Southwest Finland, Uusimaa and Ita-Uusimaa (Finland), Departement du Rhône (France), Lower Saxony (Germany), Zuid-Holland (the Netherlands), Madrid region (Spain), Vastra Gotaland (Sweden) and the East Midlands (UK).

3 Results

The PENDANT project contains an analytic component which has produced a large number of results on a variety of topics. A number of analytical outputs are included as 'Deliverables' which will be publicly available in the near future. In this paper it is only possible to provide a short selection of these, touching on overall statistics, frontal collisions, rear-end impacts, rollovers, pedestrian impacts, injury costing and EuroNCAP test conditions. Much more data will be available from the analytical outputs.

3.1 Overview

The overall number of cases on the database is shown in Table 1. It contains records for 1110 accidents, 1884 vehicles, 2369 occupants and 68 pedestrians. The relatively small proportion of vehicles or humans for which no information could be collected or recorded on the database is not included in these tallies. The number of accidents to be supplied from each group was decided prior to data collection based on resources and capability.

	Accident	Vehicle	Occupant	Pedestrian
Sweden	150	264	355	0
France	132	201	296	0
Germany	171	328	424	21
Austria	75	152	229	8
Netherlands	175	326	235	18
United Kingdom	200	290	445	2
Finland	80	126	153	6
Spain	127	197	232	13
Total	1110	1884	2369	68

Table 1: Number of cases on PENDANT database

	Car	Truck	Bus	Agricultural vehicle	Two-wheel vehicle
Sweden	248	10	6	0	0
France	194	6	0	0	1
Germany	319	9	0	0	0
Austria	144	8	0	0	0
Netherlands	306	13	3	2	2
United Kingdom	272	11	2	1	4
Finland	117	7	2	0	0
Spain	181	9	3	2	2
Total	1781	73	16	5	9

Table 2: Vehicle type

The types of vehicles on the database are shown in Table 2. The high proportion of passenger cars reflects the sampling criterion that a passenger car (manufactured from 1998 on) had to be involved in each accident.

Figure 1 shows the maximum level of injury for selected types of crashes. The proportion of serious and fatal casualties on the database is high due to the sampling requirement that at least 20% of accidents should be of MAIS 3+ severity. Some parked vehicles were unoccupied.

3.2 Frontal crashes

The tables in this section relate to two-car collisions in which the main impact was to the front end of both vehicles. There were 104 accidents of this type (necessarily) involving 208 vehicles.

The change of velocity during impact (delta-V) was calculated for 166 vehicles. The distribution of delta-V shown in Figure 2 indicates that 45% of impacts were in the 21-40km/h range.

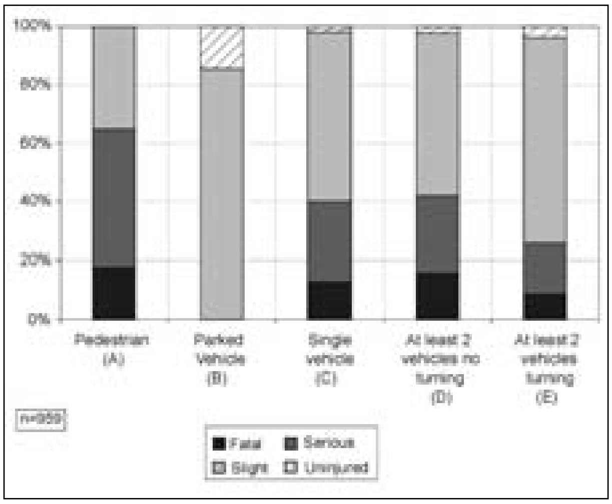


Figure 1: Crash type by injury severity

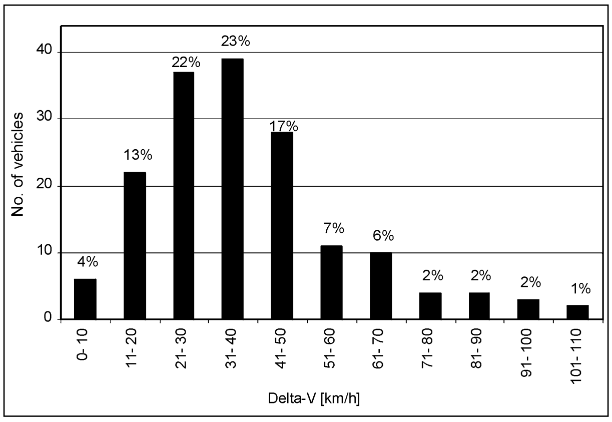


Figure 2: Change of velocity during impact for frontal crashes

Figure 3 shows the number and severity of injuries by body region according to whether there was intrusion into the vehicle or not. Very few AIS 3+ injuries occurred without intrusion, most exceptions being to the head. It does not follow that intrusion is necessarily a causal factor, as intrusion correlates with impact severity and impact severity – or more specifically the acceleration of the vehicle during impact – an result in injury independently.

Figure 4 shows the distribution of injuries by AIS severity for vehicles manufactured before 1998 (old) or from 1998 onwards (new). The proportion of AIS 3+ injuries is greater in pre-1998 vehicles, suggesting improved crashworthiness in modern vehicles.

3.3 Rear impacts

The database contains 80 cars that were struck in the rear from another vehicle, excluding two-wheelers.

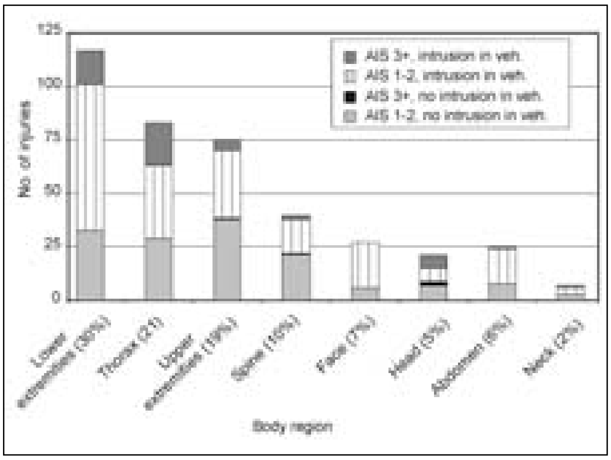


Figure 3: Number of injuries by body region for frontal crashes

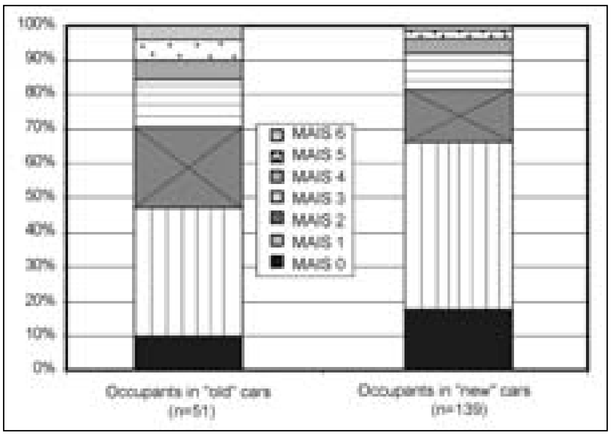


Figure 4: Distribution of MAIS by vehicle age for frontal crashes

Figure 5 shows the number of injuries by body region for males and females. The spine is by far the region most frequently affected, proportionally more often for females than males. This supports numerous studies with a similar finding.

3.4 Rollovers

There are 199 cars on the database which turned 90 degrees or more on the vehicle's longitudinal or lateral axis during the course of the accident. These events are interpreted as rollovers.

Rollovers may occur with or without significant impacts to other vehicles or roadside objects. In Figure 6 the distribution of MAIS for injured occupants is shown for non-rollovers (n=1041), rollovers without other impacts (n=65) and rollovers with other impacts (n=134).

Figure 7 shows that the proportion of vehicles in rollovers with electronic stability control (8.5%) is lower than the proportion of vehicles not fitted with this type of technology (17.9%).

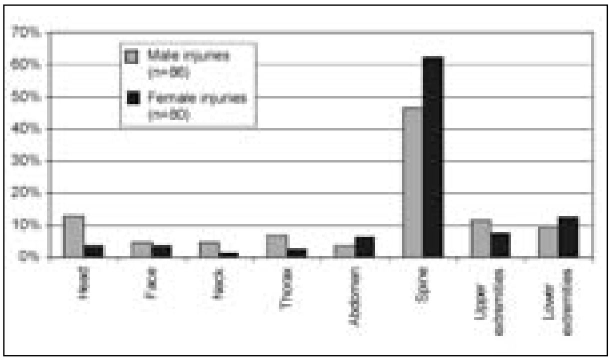


Figure 5: Number of injuries by body region for rear impacts

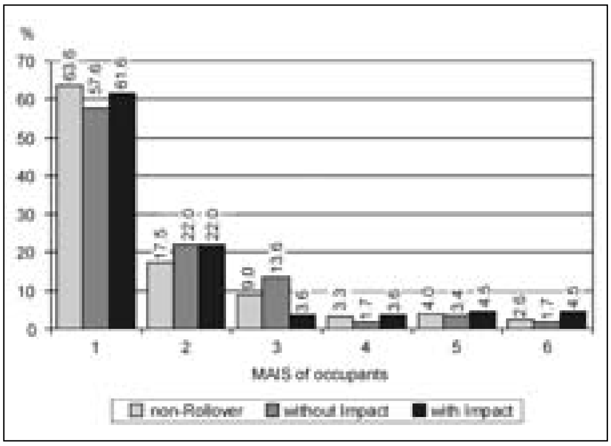


Figure 6: Occupant MAIS distribution with rollover and further impacts

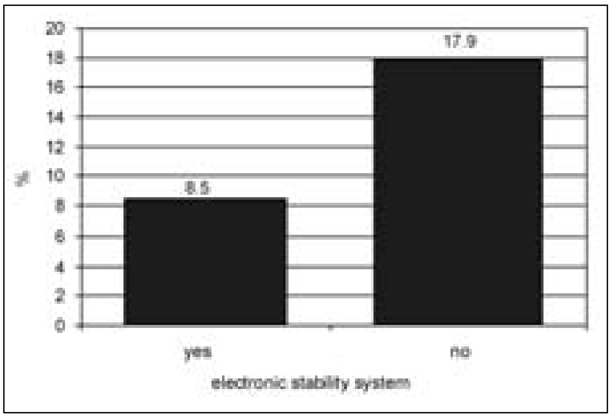


Figure 7: Proportion of vehicles with electronic stability control in rollovers

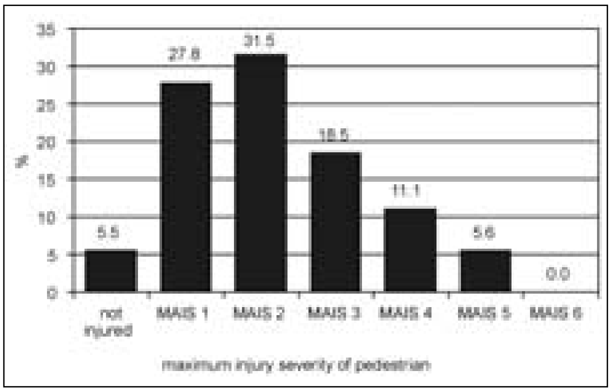


Figure 8: Pedestrian MAIS distribution

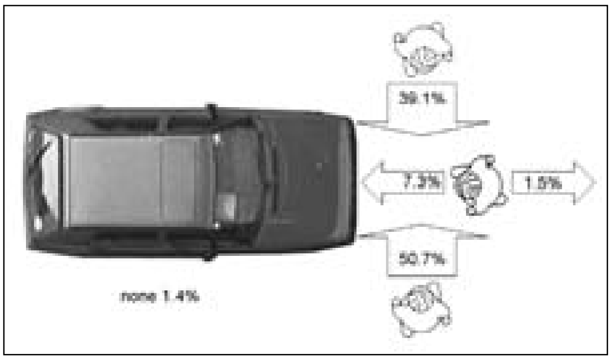


Figure 9: Walking direction (n=69)

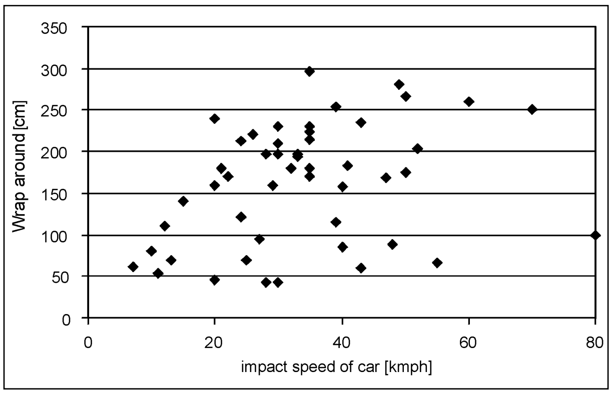


Figure 10: Impact speed and wrap-around distance (n=19)

3.5 Pedestrian

Pedestrian accidents could be sampled for PENDANT by groups in 6 countries which had at least some capability to conduct at-scene investigations. The database contains records for 69 pedestrians from 67 accidents.

Figure 8 shows the maximum injury severity for pedestrians. Approximately two-thirds were serious or fatal (MAIS 2+) casualties.

The walking direction of the pedestrian relative to the striking vehicle is represented in Figure 9. Half of the pedestrians (50.7%) approached the vehicle from its right-hand side. This means 'directly' from the kerb without reaching the centre of the road for most cases as the majority of the sample (67 pedestrians) are from countries where vehicles travel on the right-hand side of the road.

The wrap-around measurement is the distance around the contour of the car body from the road surface to the point of impact of the pedestrian's head Figure 10 shows that measurements approaching 300cm were observed and how these relate to the impact speed of the car.

3.6 Injury costing

A willingness-to-pay technique using a UK injury cost model was applied to the PENDANT database to attain an estimation of the cost of injuries. The method is described in detail in the final report of the project [2].

Figure 11 and Figure 12 provide a comparison of costs per body region for cars manufactured before and after 1998, based on the PENDANT sample for all crash types. The proportional cost of head injuries is highest in both groups at around 32-33%. This is followed by spine, thorax and lower extremity, in a slightly different order, for both newer and older cars.

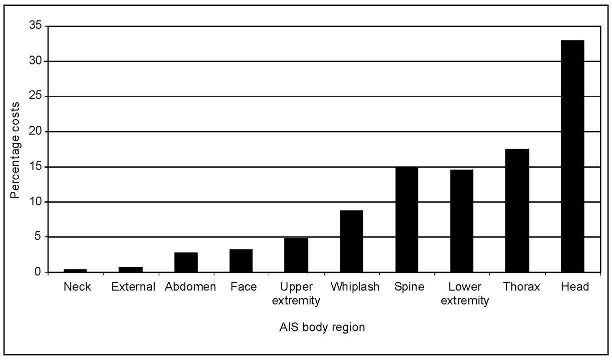


Figure 11: Cost of injury by body region for cars manufactured before 1998

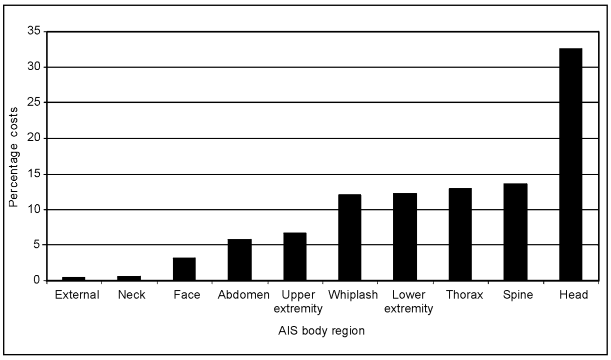


Figure 12: Cost of injury by body region for cars manufactured after 1998

3.7 EuroNCAP

One application of accident data is to develop and assess crash test conditions. The EuroNCAP frontal test uses 64km/h with 40% overlap between the barrier and front-end of the vehicle.

Figure 13 and Figure 14 show the distribution of Energy Equivalent Speed (EES) and overlap for vehicles in the sample that had frontal impacts. EES is a measure of the energy absorbed by a vehicle expressed as speed and is roughly comparable to the impact speed of a crash test

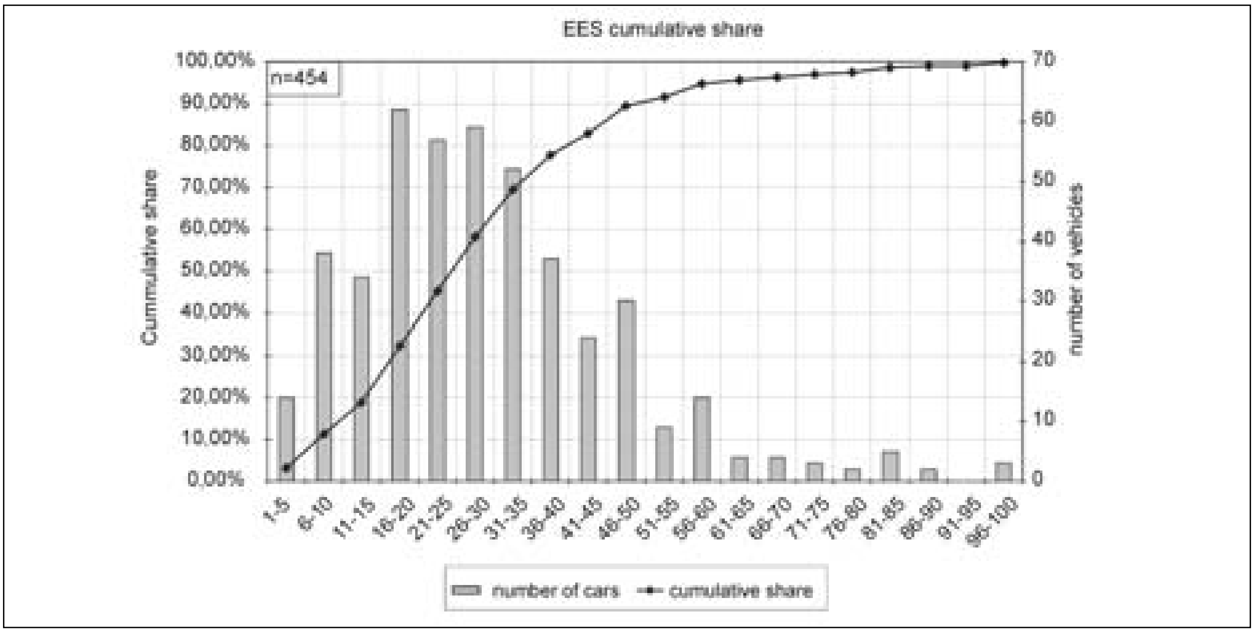


Figure 13: EES for vehicles in frontal impacts (n=454)

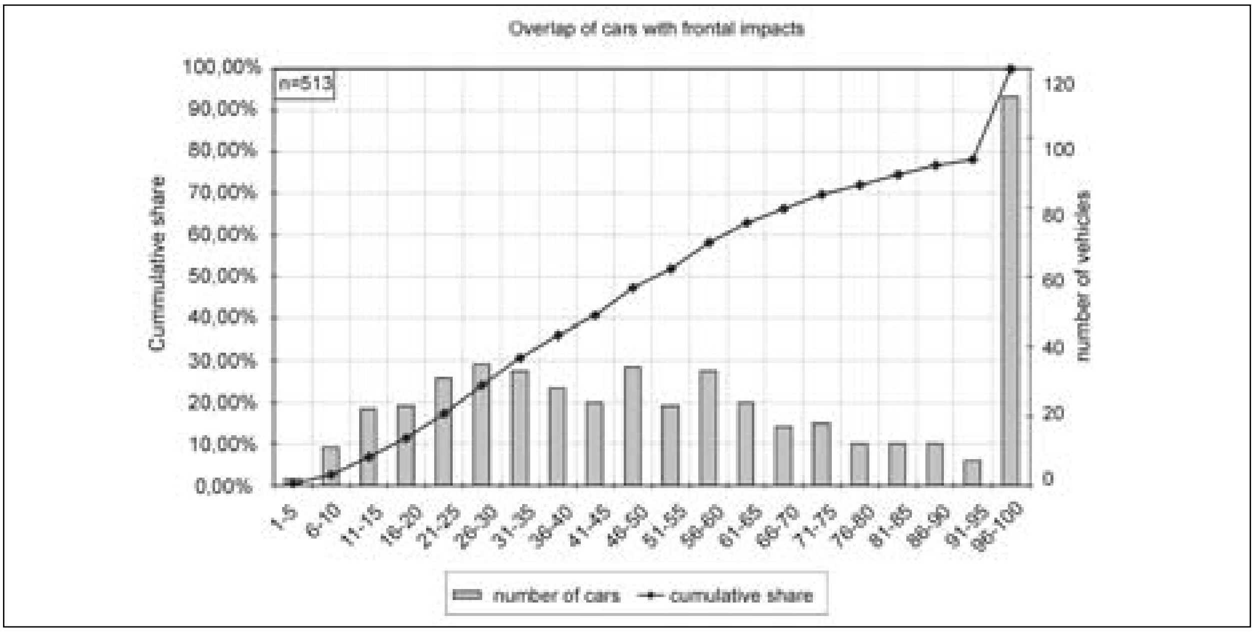


Figure 14: Overlap for vehicles in frontal impacts (n=513)

vehicle. It can be seen that 64km/h is around the 95-percentile level of impact severity and that there is a wide dispersion of overlap levels, with the EuroNCAP configuration (40%) lying in the central region of the range.

4 Discussion

The results presented in this paper are a small selection of those derived for the final report of the PENDANT project. They are intended to give an indication of the variety and interest of the study. The results touch on topical themes regarding front, rear, rollover and pedestrian accidents, injury costing, and comparison of real accident conditions to crash test configurations. Thus Figure 4 suggests improved crashworthiness in modern cars in frontal impacts; Figure 5 confirms the importance of whiplash in rear impacts, particularly among women; Figure 6 bears on the question whether rollovers without further impacts are benign events, while Figure 7 points to a possible beneficial influence of electronic stability control on rollover. The data on pedestrian impact speed and wrap-around distance in Figure 10 are relevant to current considerations on pedestrian test conditions and vehicle design. The application of an injury cost model to the PENDANT data in Section 3.6 suggests that head injuries remain a top priority in accidents involving modern cars. Finally, the results in Section 3.7 indicate that EuroNCAP frontal test is a severe test at 64km/h but appropriately configured at 40% overlap.

It must be stressed that the number of cases in the PENDANT database is too small to guarantee statistical representativeness within the European Union. With the expansion of the European Union from 15 to 25 members during the course of the study, it is clear that having 8 countries involved in Europe-wide data collection is sub-optimal. If PENDANT has demonstrated that the protocols for in-depth accident investigation developed in STAIRS can be implemented across Europe, a natural evolution would be to widen out to a expanded study across the EU-25, collecting baseline in-depth data through a routine operation to achieve full representativeness of the accident situation in the region.

The PENDANT project has raised many issues as potential priorities for European vehicle and road safety. These include:

- Further definition of injury mechanisms in front and side impacts, particularly for whiplash, chest injury and lower extremity injury.
- Evaluation of the effectiveness of advanced safety systems already installed, together with prediction of the effectiveness of emerging technologies.
- Consideration whether the priorities for secondary safety will remain as they are now as primary safety technologies penetrate the vehicle market.
- Further in-depth accident studies, including individual case reviews to fully evaluate the nature and source of injuries.
- A review of current accident studies to ensure that the methodology used in each allows satisfactory answers to outstanding research questions.
- Development of a rollover test including the potential to prevent ejection.
- Assessment of occupant protection systems in multiple impacts.
- Examination of the long-term consequences of crashes, injury costs and impairments.
- Evaluation of the potential for whiplash injury prevention from new seat design.
- Continued collection of enhanced data for accidents involving children with a view to the development of knowledge on child injury biomechanics.

5 Conclusion

The PENDANT study has demonstrated that the common protocols for collecting in-depth accident data originally developed in the STAIRS project can be implemented across Europe and that the results are useful to the development of EU vehicle and road safety policy. With the expansion of the EU to 25 countries, a natural evolution would be to instigate a routine data collection operation across a wider region, sampling sufficient cases to guarantee statistical representativeness.

A variety of issues have emerged as potential priorities for future research and action. The PENDANT database can support further extensive analysis than has been possible to date, and this would contribute further support to the formulation of European safety policy.

References

1 G. VALLET, B. LAUMON, J.L. MARTIN, P. LEJEUNE, P. THOMAS, R. ROSS, I. KOSSMANN, D. OTTE, B. SEXTON: STAIRS – Standardisation of Accident and Injury Registration, final report, Contract No RO-96-SC.204, February 1999

2 A. MORRIS et al.: PENDANT Work Package 2, final report, forthcoming (September 2006)

H. Hautzinger
Institute of Applied Transport and Tourism Research (IVT), Heilbronn, Germany

Multi-Level Statistical Models for Vehicle Crashworthiness Assessment – An Overview

Abstract

Empirical vehicle crashworthiness studies are usually based on national or in-depth traffic accident surveys: Data on accident-involved cars/drivers are analysed in order to quantify the chance of driver injury and to assess certain risk factors like car make and model. As the cars/drivers involved in the same accident form a 'cluster', where the size of the cluster equals the number of accident-involved parties, traffic accident survey data are typical multi-level data with accidents as first-level or primary and cars/drivers as second-level or secondary units (car occupants in general are to be considered as third level units). Consequently, appropriate statistical multi-level models are to be used for driver injury risk estimation purposes as these models properly account for the cluster structure of traffic accident survey data. In recent years various types of regression models for clustered data have been developed in the statistical sciences. This paper presents multi-level statistical models, which are generally applicable for vehicle crashworthiness assessment in the sense that data on single and multiple car crashes can be analysed simultaneously. As a special case of multi-level modelling driver injury risk estimation based on paired-by-collision car/driver data is considered. It is demonstrated that assessment results may be seriously biased, if the cluster structure inherent in traffic accident survey data is erroneously ignored in the data analysis stage.

Introduction

Vehicle crashworthiness, i.e. the ability of a vehicle to protect its own occupants in collisions, is an important research subject in the traffic safety sciences. It is, of course, a theoretical concept which can be specified in several different ways. Basically, vehicle crashworthiness is to be measured by occupant injury risk given accident involvement. However, as injury information may not necessarily be available for all occupants of accident-involved vehicles, crashworthiness is frequently quantified simply by driver injury risk: the higher the driver's probability to be injured, the lower the vehicle's crashworthiness.

The injury status of accident-involved drivers is affected by many characteristics of the driver and his or her vehicle. In addition, factors like collision speed, mass of opponent vehicle and so forth play an important role. Among the numerous determinants of driver injury risk, the risk factor 'make and model of the car driven' is of special and sometimes even primary interest. The latter will, for instance, be the case in car safety rating based on real-world crash data. Although this paper focuses on the assessment of car make and model as a determinant of driver injury, the methods presented here can easily be transferred to the analysis of any other risk factor of interest.

Investigations in vehicle crashworthiness may be viewed as special cases of epidemiological studies as they deal with the distribution and determinants of a specific 'disease' (=injury due to accident involvement) in a specific human population (=accident-involved car drivers). Descriptive crashworthiness analyses are conducted in order to estimate the average safety level of different car models; the results of such analyses may, for instance, be of interest for the motor car insurance industry. Analytical (also termed 'aetiological') studies designed to measure the partial effect of car make and model on driver injury risk preferably correspond to the car buyer's perspective.

Partially based on results of the SARAC project [1] the following topics are treated in the sequel:

- Estimating absolute and comparative chance of driver injury for cars grouped by make and model.
- Testing association between risk factor car make and model and criterion variable car driver injury status (crashworthiness comparisons between different groups of cars).
- Measuring comparative chance of car driver injury in the case of multi-level data (random effects probit and fixed effects logit models).
- Adjustment of group-specific injury risk rates for third variables (confounding factors).

- Paired-by-collision car/driver data as a special case of multi-level traffic accident data.

The paper gives an overview of elementary and more advanced statistical methods for vehicle crashworthiness assessment taking explicitely account of the multi-level structure of traffic accident data. The assessment of vehicle aggressivity defined as the degree to which injury is inflicted upon occupants of the vehicle or road user with which the 'subject' car crashes will not be treated here.

Basic Concepts

Accident survey as the basic study type for crashworthiness investigations

Empirical crashworthiness investigations belong to the class of observational studies: data are collected on real-world accidents and accident-involved cars which provide information on car make and model and car driver injury status but also on third variables which might affect driver injury risk. Typically, a certain traffic accident survey[1] is the data source and thus the study design of a crashworthiness investigation may be characterized as an ex-post-facto approach.

In many practical situations these surveys will have been conducted by a national statistical office and thus the accident survey under consideration will frequently be a complete census in the sense that all police-recorded accidents are contained in the database. In some cases, however, the empirical data may have the character of a sample, e.g. when they have been collected in a local or regional in-depth accident investigation under a specific sampling plan. As usually for each accident recorded in the survey empirical data on all accident-involved cars are collected, a traffic accident survey normally is a cluster survey with accidents as primary and accident-involved cars as secondary units.

Surveys are referred to as cross-sectional investigations when they provide data for a limited study period. In the case of traffic accident surveys, however, the system of data collection can frequently be considered as a permanent survey. Therefore, incidence[2] of injury (number of cases of injury within a specified period of time) caused by traffic accidents may be measured for consecutive time periods (e.g. weeks, months or years).

Measuring the risk factor car make and model

In epidemiology[3] any potential determinant of the disease under study is termed risk factor. In the context of crashworthiness assessment, of course, car make and model is the risk factor of primary interest. It is important to note that 'car make and model' is a theoretical construct which needs to be specified carefully. Obviously, one may consider car make and model as a complex attribute of a vehicle summarising all its physical and design properties. In this case vehicle characteristics like length, mass and body style of car are already 'contained' in the vehicle attribute car make and model. When the above concept is applied, it would make no sense to consider crashworthiness as a function of car make and model and mass of car, as car mass is simply one of the constituent properties of a given car model.[4] Under such a perspective the car mass effect on crashworthiness (mass of the 'subject' or 'focus' car itself, not mass of the opponent car!) simply cannot be separated from the effect of car make and model.

Alternatively, car make and model may be considered as an attribute characterising only the car's design properties and secondary safety fittings. In this case the car's purely physical properties like length and mass could be assumed

---

1 In addition to surveys, so-called case-control studies are also widely used retrospective observational types of investigation. As case-control study is always based on two different samples, one sample of 'cases" (persons with a specific disease) and a second sample of 'controls" (persons without the disease). These two groups are compared with regard to the risk factor. From a methodological point of view surveys are normally preferred to case-control studies, especially when the survey is a representative sample from the population of interest or even a complete census. It will, however, be shown later in this paper that it might well be advantageous to build a database from a standard traffic accident survey which formally corresponds to the database of a so-called matched case-control study.

2 In epidemiological studies, in addition to incidence one is often also interested in the prevalence of a certain disease (number of existing cases of disease at a particular point in time). As accidents are events in time and space and not objects or subjects (like patients), the concept of prevalence does not apply to crashworthiness investigations.

3 The basic concepts and methods of epidemiology are presented here following [2].

4 For instance, when drugs A, B,... are compared in clinical trials it is not common to consider the amount of a certain active substance contained in the drugs as a separate variable. Consequently, no adjustments or corrections for this variable are made.

to be separate determinants of vehicle safety. Such a concept might be useful if car make and model is defined in the broader sense of 'car model group' such that cars belonging to the same model group may differ in mass (variation of vehicle mass within car model group). However, even if we assume car mass and car model group to represent different aspects of a vehicle, it is clear that car mass is largely determined by car make and model. As this dependency may be considered as a causal relationship ('the vehicle is heavy because it is a Mercedes S class'), it is at least questionable whether driver injury risk should be adjusted for mass effects in order to measure the pure effect of the car's structure, design and secondary safety fittings on occupant protection.

Obviously, the risk factor car make and model is a categorical variable. The main purpose of vehicle crashworthiness assessment is to estimate an appropriate index of crashworthiness for each category of cars. In the simplest case only two categories are distinguished. In this situation one often speaks of 'subject' car model (e.g. VW Golf 4) and 'other' car model (e.g. not VW Golf 4) corresponding to the usual 'exposed/unexposed' dichotomy. Sometimes, however, we may explicitely consider several different car models which means that the risk factor under consideration has a whole set of possible categorical (i.e. unordered) outcomes. It is not uncommon to distinguish up to about 150 different car models in a single crashworthiness study.

Measuring car occupant injury status

Vehicle crashworthiness has been defined as the ability of a car to avoid injury to its own occupants in collisions. Thus, occupant injury status is the dependent or criterion variable of any crashworthiness study. 'Injury', of course, may be measured in quite different ways ranging from coarse classifications based on police reports to rather complex injury scales (AIS, ISS). Ideally, one would like to have a clinical definition of what is meant by 'injury' which can be tested by objective evidence. In many practical situations, however, the vehicle safety analyst has to rely on police reports or insurance files, where the validity and consistency of diagnostic criteria is at least questionable.

One could, of course, decide to use mortality (death due to crash involvement) as the criterion variable. This, however, would result in a significant reduction in the number of cases of 'injury' to be found in the population of accident-involved car occupants. Therefore, one usually moves further down the hierarchy of severity of injury:

- died,
- hospitalized,
- diagnosed or self-reported accidental injury.

Statistical analysis of driver injury risk is considerably simplified if the crude binary attribute 'driver injured: yes/no' is used to describe accident outcome. One can, however, also distinguish several (ordered) levels of injury severity ranging from 'uninjured' to 'killed' in the case of police-recorded data or from AIS 0 to AIS 6 when in-depth data are available.

It should be noted that crashworthiness assessment results may depend on the accident outcome measure adopted. Therefore, careful consideration of the injury status variable used is necessary when comparing different vehicle safety assessment approaches. As already stated above, vehicle crashworthiness is frequently measured simply by car driver injury. Only in a few studies both driver and (front) passenger injury is considered. Not surprisingly, the choice of the accident outcome variable is often dictated by data availability.

Measuring the chance of driver injury incidence

Vehicle crashworthiness assessment aims at evaluating the chance that an accident-involved driver of a certain car model (the 'subject' car model) is injured. The most basic epidemiological measure is the risk of injury, i.e. the probability of an accident-involved driver being injured given that he or she drives a 'subject' car. Like in other fields of safety research, however, various alternative risk concepts are applicable in vehicle crashworthiness studies (absolute and relative risk, odds and odds ratio).

Classical methods for estimating risk measures from survey data are based on the assumption that the study units (in our case accident-involved vehicles/drivers) have been selected by simple random sampling. In the following chapter it will be demonstrated that this assumption is by no means valid in crashworthiness studies. Rather, the study units are grouped or clustered in a natural way. This characteristic property of empirical traffic accident data calls for specific methods of risk estimation.

Crashworthiness Assessment Based on Multi-Level Car/Driver Data from Traffic Acident Surveys – The General Case

Multi-level structure of the population at risk

In studies on vehicle crashworthiness the universe of accident-involved cars or, more precisely, the universe of 'accident involvements of cars' has to be considered as the population at risk. Of course, this population must as usual be well defined with respect to factual, spatial, and temporal characteristics. It is important to note that the elements of the population at risk are neither fixed subjects nor objects but rather events occurring in time and space.

Obviously, a collision of two cars corresponds to two different accident involvements of cars which, however, refer to the same accident. In this situation one may speak of 'paired-by-collision vehicle/driver data'. More generally, it can be said that the population at risk has a multi-level structure with accidents (single and multiple vehicle accidents) as first-level units, accident-involved vehicles as second-level units and occupants of accident-involved vehicles as third-level units. The first level units, i.e. the accidents, may be considered as clusters of accident-involved cars where the size of the cluster (1, 2, 3,…) corresponds to the number of parties involved in the crash. This multi-level or cluster structure of the population at risk must be taken into account in any methodologically sound crashworthiness investigation.

As a prerequisite for vehicle crashworthiness assessment, information on the following characteristics is needed for each selected element of the population at risk, i.e. for each accident-involved car in the sample:

- injury status of car driver (criterion variable),
- make and model of car (risk factor to be assessed),
- other factors which might affect the criterion variable (concomitant variables).

Risk and relative risk of car driver injury

The purpose of crashworthiness assessment is to evaluate the chance of car driver injury in case of an accident. An appropriate quantitative measure is the risk of car driver injury, i.e. the probability of the car driver being injured given that the car belongs to a particular group of vehicles ('subject' car model or, more generally, group of 'exposed' study units). The risk of car driver injury (also termed absolute risk) describes the relationship between a specific car make and model and car driver injury status. This, however, is not sufficient for assessing the risk factor to injury outcome.

As in other fields of evaluation research a comparison group is required which, for instance, may be the group of accident-involved cars which do not belong to the car model category under consideration ('other' car model or, more generally, group of 'unexposed' study units). This leads to the definition of relative risk as the ratio of injury risk for the drivers of a particular car model to the injury risk for the drivers belonging to the comparison group. When several different car models are considered simultaneously, one category is chosen to be the base or reference category and the analyst compares all other categories to this base.

Odds and odds ratio of car driver injury

However, risk as a probability is not the only possibility of specifying 'chance'. An alternative specification is called the odds. The odds measure the number of times accidental injury occurs relative to the number of times it does not. The odds can be calculated for different groups of vehicle/driver units. In car safety rating one is interested in the ratio of the odds for a particular car model to the odds of a comparison group which, for instance, may consist of all other car models. The corresponding measure is called odds ratio.

It is important to note that in epidemiology and other fields of applied statistics researchers take 'odds' and 'odds ratio' to refer to the chance of disease (accidental injury) incidence just as they do 'risk' and 'relative risk'. In practice, the odds as such are rarely of interest, and the odds ratio is generally quoted alone. In vehicle crashworthiness studies one can, of course, think of several alternative ways to measure car driver injury risk. Clearly, however, only statistically sound concepts of specifying 'chance' of occupant injury are acceptable. Careful interpretation of the risk measure used is necessary.

Relative risk and odds ratio as measures of association between car make and model and car driver injury

It should be stressed again that the relative risk and the odds ratio are meaningful measures of association between risk factor car make and model and car driver injury. Both quantities measure the relative chance of driver injury for a particular subject car model, compared to a certain base category or reference group of cars: if the crashworthiness of the subject car model does not differ from the crashworthiness of the reference group of cars, one can expext the relative risk and the odds ratio to be around unity (corresponding to 'no association' between risk factor and driver injury status).

As crashworthiness assessment normally aims at some ranking of car models, it can be said that the calculation of the relative risk and the odds ratio is fundamental to any car safety rating system. Obviously, both the relative risk and the odds ratio have to be estimated from empirical data collected in accident surveys. Subsequently, it will be shown that due to the specific nature of the population at risk (clustering of study units) the classical approaches to measuring relative chance of driver injury are not suitable.

Estimating relative risks and odds ratios in the case of multi-level data

Why the classical (unmatched) approach is not appropriate

According to epidemiological standards a given categorical risk factor is assessed by computing a 95% confidence interval for the population value of the relative risk or the odds ratio (subject car model compared to reference car model). If the confidence interval does contain unity, one concludes that the risk factor car model has no effect on driver injury. If the lower (upper) limit of the confidence interval is above (below) unity, one concludes that the injury risk for subject car model drivers is higher (lower) compared to the reference group of cars. For computational details see [2], Chapter 3.

The classical approach outlined above assumes that a simple random sample of units has been drawn from the population at risk. Under simple random sampling the sample inclusion probability of a specific unit a is not affected by the drawing of some other unit b from the population. This, however, is not the case in vehicle crashworthiness studies due to the multi-level structure of the population. If, for instance, one car involved in a specific two-car accident is in the sample, the second car involved in the same accident will automatically be also in the sample. Thus, for any two-car crash the corresponding accident involvements of cars (say car 1 and car 2) must be considered as a 'cluster' in the sense that – irrespective of car make and model – the injury status of the two drivers is not independent: if driver 1 is injured (uninjured), driver 2 also tends to be injured (uninjured) for obvious reasons. The same argument holds for accidents where more than two vehicles (more generally: 'parties') were involved.

Risk factor assessment based on multi-level models

As there is a known clustering within the accident involvement data, a multi-level model will be appropriate for assessing the risk factor car make and model. In the context of crashworthiness assessment multi-level modelling means that regression models with accident-specific parameters are used. These accident-specific parameters which sometimes are also called 'effects' may be assumed to be fixed or random.

If the driver injury status variable is binary, the fixed effects logit model or the random effects probit model can be applied with driver injury status as the dependent and risk factor status (car make and model) as the explanatory variable. See, for instance, [3] and [4]. As usual, the different categories of car make and model are represented by dummy variables in the logit or probit model. From these models one obtains point and interval estimates of the relative chance of driver injury for one or more 'subject' car models compared to a given 'reference' car model. In contrast to the classical approach these estimates account for the clustering within the accident involvement data. Another substantial advantage of these models is that additional variables can be included thus adjusting risk estimates for confounding factors. Subsequently, the random effects probit model is briefly described.

Let accidents be labelled by the index $i(i=1,\ldots,n)$ and the cars within accident i by the index where $j(j=1, \ldots, m_i)$ where $m_i=1, 2, 3,\ldots$. Then, for the observable dichotomous driver injury status variable, i.e. for the dependent variable

$$y_{ij} = \begin{cases} 1 & if\ \ driver\ \ j\ in\ accident\ \ i\ is\ injured \\ 0 & otherwise \end{cases}$$

a probit model with random effects could be developed, the structure of which is

$$y_{ij} = \begin{cases} 1 & if\ \ y^*_{ij} > 0 \\ 0 & otherwise \end{cases}$$

where

$$y^*_{ij} = \mu + \sum_k \beta_k x_{ijk} + u_{ij}$$

is a non-observable ('latent') continuos variable to be interpreted, for instance, as a combined index of strength and effect of the forces acting upon driver *j* in accident *i*. If this index exceeds a certain threshold value (zero), the event 'driver is injured' will be observed. The latent variable is assumed to depend on a set of indicator variables χ_{ijk} (k=1, 2, …) attaining the value 1 or 0 if category *k* of the risk factor car make and model is present or not present at the *j*-th car within the *i*-th accident and a random error term

$u_{ij}=a_i + \varepsilon_{ij}$

consisting of an accident-specific random component a_i and a purely random component ε_{ij}. As can be seen, a_i allows for random variation of the latent variable at the accident level, whereas ε_{ij} accounts for random effects at the car/driver level. Regarding the random effect a_i it is assumed that this variable is normally distributed with mean 0 and variance σ^2_α. As usual it is assumed that the component ε_{ij} is normally distributed with mean 0 and variance $\sigma^2_\varepsilon = 1$.

The above variance component model implies that for any given accident *i* the latent variables γ^*_{ij} (*j*=1,... m_i) and thus the observed injury outcomes of the drivers involved in the same accident are positively correlated with correlation coefficient $\gamma = \sigma^2_\alpha / (\sigma^2_\alpha + 1)$. This property makes the model suitable for analysing clustered data as is the case in crashworthiness assessment.

Using empirical crash involvement data (*n* accidents, $m = \sum_{i=1}^{n} m_i$ accident-involved cars/ drivers) one can estimate by the maximum likelihood method

- the model constant μ
- the parameters β_k associated with the different categories of the risk factor car make and model and
- the coefficient of correlation γ.

By definition, the parameter associated with the reference car model category is equal to zero. Therefore, a positive (negative) sign of β_k indicates that the accident consequences are more (less) severe for drivers of car model category k compared to drivers of the reference group of cars. As the standard errors of the parameter estimates can be estimated, it is possible to compute confidence intervals and to test hypotheses about the parameters and thus hypotheses about the crashworthiness of different car models.

Models of the type outlined above can be estimated using appropriate statistical software. The author has estimated random effects probit models by means of LIMDEP procedure PROBIT in a mobility behaviour study (car use of persons within households as a function of characteristics of the person and the household). See [5]. The problem structure in crashworthiness studies is quite similar (injury of drivers within accidents as a function of characteristics of the car/driver and the accident).

It appears that the estimation of the relative chance of driver injury may lead to erroneous results if the clustering within the accident involvement data is not taken into account in the data analysis stage. This will be shown in the following chapter, where a practical example is presented. To the author's knowledge, general multi-level models of the type described above have not yet been applied in vehicle crashworthiness assessment using at the same time data on single car, two-car and multiple car accidents. However, for the important special case of two-car accident data ('paired-by-collision vehicle/driver data') examples of multi-level models can already be found in the literature which will be quoted later.

Crashworthiness Assessment Based on Paired-by-Collision Car/Driver Data

Rationale for using two-car accident data only

Several existing vehicle safety rating methods[5] restrict themselves to analysing data on two-car accidents only. From a methodological point of view this approach may be interpreted as a so-called 'matched pairs design' frequently encountered in epidemiological studies. Typically, the restriction to two-car accidents is to minimise distortion which would be caused to the estimates of driver injury risk if, for instance, a particular car model had a high proportion of collisions with much larger vehicles such as lorries or busses. As will be seen below there are, however, even more convincing arguments in favour of the use of paired-by-collision car/driver data for crashworthiness assessment purposes.

As already stated above the restriction to two-car accidents corresponds to a matched pairs design (also termed '1:1 matching' or 'pair matching'): the cars involved in the same accident are considered as a single matched pair rather than two independent observations. Considering pairs of cars has the advantage of high internal validity[6] since all observed and unobserved (!) characteristics of the accident itself (time, location, weather conditions etc.) are the same for both accident-involved cars and, therefore, these characteristics cannot account for possible differences in the injury risk of the two drivers involved in the accident. Consequently, 'confounding' is reduced and the 'pure' effect of car make and model on the chance of car driver injury can be measured more precisely.

Another very attractive feature of the matched pairs design is that it can equally been applied to accident databases with and without damage-only accidents. This is because accidents where both drivers are not injured or both drivers are injured (so-called concordant pairs) tell nothing about the relative risk of driver injury (subject car model compared to other car model). Practically all in-depth accident databases and many police-recorded accident data sets do not cover accidents with material damage only. In all these cases it is obviously not possible to estimate the absolute risk of driver injury because a substantial part of the accident-involved non-injured drivers is missing in the accident database. All one can do is to estimate the comparative chance of driver injury which can best be accomplished under a matched pairs design.

When adjustment for confounding is made at the design stage of the study by choosing the concept of matched pairs, this must be taken into account in the stage of data analysis. A matched pairs study requires a matched pairs analysis, which can be more complex both to understand and compute. See [2], Chapter 6, for a general presentation. For statistical details of matched studies in vehicle safety research see [1]. As an example of proper application of matched pairs analysis methods (conditional logistic regression models for paired data) in the context of estimating the comparative chance of driver injury see [7].

The decision on the statistical method to be used for data analysis depends on the answers to the following questions:

- Is the assessment of the risk factor under consideration to be made without or with adjustment for confounding car- and driver-specific[7] variables?
- Is driver injury status a binary variable or is it measured on an ordinal scale with several levels?
- Are we mainly interested in testing association between risk factor and driver injury?
- Is estimation of the comparative chance of driver injury a main concern of the study?

Depending on study purposes and scaling of the variables, the statistical tool box offers various methods for vehicle crashworthiness assessment in the case of paired-by-collision car/driver data.

The candidate approaches can be broadly classified into statistical models with population-averaged and models with accident-specific parameters. The two approaches differ in the way of modelling the dependence between the injury status of the two-car drivers belonging to the same accident. The first approach leads to the class of log-linear models of driver injury in two-car

5 A detailed description of existing car safety rating methods can be found in a specific SARAC report prepared by the author. See [6]. It can be said that all safety rating methods described in this report ignore the clustering of car/driver data.

6 Obviously, the external validity of vehicle crashworthiness assessment is reduced by analysing paired-by-collision car/driver data only, since a substantial part of the population of all accident involvements of cars (especially single car crashes, crashes against freight transport vehicles etc.) is ruled out. As the severity of these crashes tends to be above average, this is an obvious weakness of the matched pairs design.

7 Adjustment for accident-specific covariates is automatically made due to matching.

accidents, the second preferably to so-called fixed effects models of driver injury for cars/drivers matched in pairs.

In various fields of applied statistics fixed effects models proved to be well suited for analysing matched pairs data, especially data from matched case-control or matched cohort studies. It turnes out that this is also valid for crashworthiness studies based on two-car accident data.

Crashworthiness assessment without adjustment for car- and driver-specific variables

When no adjustment for confounders is to be made, paired car/driver data can always be displayed in a square two-dimensional contingency table, where the two dimensions of the table (rows and columns, respectively) correspond to the two accident-involved cars/drivers. If driver injury status as well as car make and model are binary variables, a 2x2 table will arise. For the construction of this 2x2 table two different possibilities of crosstabulating accidents exist:

- Matched cohort study design: Accidents by injury status of subject car driver (rows) and injury status of other car driver (columns).
- Matched case-control study design: Accidents by car make and model of injured driver (rows) and car make and model of uninjured driver (columns).

The null hypothesis of no association between the risk factor car make and model and the criterion variable car driver injury status can be tested using a so-called symmetry test. When dealing with 2x2 tables McNemar's test will normally be appropriate.

When more than two levels of driver injury are to be distinguished, the matched cohort design is appropriate. If more than two categories of car models are to be assessed, the matched case-control design with injured drivers as cases and uninjured drivers as controls is to be chosen by the analyst. In both situations the empirical accident frequency data can be displayed in rxr tables. For rxr tables Bouwker's test is the appropriate statistical method for testing the hypothesis of no association.

For matched studies the odds ratio is the generally accepted measure of comparative chance of driver injury (injury odds for subject car driver divided by injury odds for other car driver). Under a matched pairs design the odds ratio can be estimated from the corresponding 2x2 table. It turns out that for paired data the estimate of the odds ratio[8] only depends on the two off-diagonal elements of the 2x2 table[9]. The corresponding estimate is often termed matched odds ratio. When under a matched case-control study design several car models are to be distinguished, the empirical accident frequency data are displayed in a rxr table. In this situation the odds ratio can be calculated for all combinations of car models (e.g. combinations A/B, A/C and B/C when three car models A, B, C are considered).

Under a matched design confidence intervals for the population value of the odds ratio can be computed using the F-distribution. It is important to note, that the choice of the odds ratio estimate (matched odds ratio versus cross-product ratio) does not only affect the confidence interval but also the point estimate of the driver injury odds ratio. When pairing is ignored, the odds ratio estimate may be seriously biased. See the example below.

Crashworthiness assessment with adjustment for car- and driver-specific variables

When the adjusted odds ratio for the risk factor car make and model is of interest (adjustment for confounding car- and driver-specific variables), the above analysis of two-dimensional contingency tables is no longer appropriate. Rather, specific regression models for car driver injury status are needed which in addition to the risk factor also contain confounding factors as explanatory variables. The classical logistic regression model, of course, is not suitable as the injury status of the two drivers involved in the same accident can never

---

8 Maximum likelihood estimate under the fixed effects logit model (model with accident-specific parameters accounting for the pairing of units).

9 Under an unmatched design the proper estimate of the odds ratio is the so-called 'cross-product ratio" defined as the product of the two main diagonal elements divided by the product of the two off-diagonal elements. For 2x2 tables the cross-product ratio is the maximum likelihood estimate of the odds ratio under the classical logistic regression model (model with population-averaged parameters). This model is suitable when no pairing of units is present in the data set. The latter would, for instance, be the case if for some reason only single car accidents are to be analysed. In this situation rows would correspond to car models (subject/other) and columns to driver injury status (injured/uninjured).

be regarded as two independent variables. Rather, the two-level structure of the data (level 1: accidents; level 2: accident-involved cars/drivers) must be taken into account.

Among several alternative stochastic models the fixed effects logit model appears to be most suitable for the statistical analysis of paired-by-collision car/driver data, especially when theoretical as well as practical considerations play a role. In order to obtain empirical estimates of the regression parameters and estimates of the corresponding (adjusted) odds ratios one can transform the fixed effects logit model in a certain way (called 'conditioning out accident-specific fixed effects') leading to the so-called conditional logistic regression model for matched pairs data. This model can be estimated using standard logistic regression software. Very briefly, the method for estimating the parameters associated with the categories of the risk factor car make and model and the parameters associated with the confounding factors can be described as follows:

- Eliminate all accidents from the data set where injury status of the two drivers does not differ.
- Create difference scores for all car- and driver-specific covariates (value for car 1 minus value for car 2).
- Use maximum likelihood to estimate the logistic regression predicting injury status of driver of car 1 with the difference scores as predictor variables in a model with no intercept.

Finally, it is stressed again that from paired car/driver data one cannot estimate the absolute risk of driver injury but only the comparative chance of driver injury. This, however, is completely sufficient in many situations, especially in vehicle safety studies aiming at a ranking of various car models with respect to crashworthiness.

Practical examples of driver injury odds ratio estimation based on paired-by-collision car/driver data

Description of the empirical database

Subsequently, two different car models, say car model A and car model B[10], are distinguished and driver injury status is measured by the binary variable 'driver injured yes/no'. As only car-to-car crashes are considered, each cluster consists of exactly two members (accident-involved cars). If in each two-car accident one car is arbitrarily labelled as 'car 1' and the other as 'car 2', one obtains 16 different subpopulations of accidents.

Table1[11] shows these subpopulations. The sizes of the 16 subpopulations which are also given in the table have been taken from German road traffic accident statistics 1998-2002 (car model A=Golf 2, car model B=Golf 3). As one can see, in total 3973 two-car accidents were registered by police, where a model A car collided with a model B car ('A/B crashes') or where cars of the same make and model crashed ('A/A crashes' and 'B/B crashes', respectively).

It will be shown how the driver injury odds ratio for car model A compared to car model B can be estimated taking account of the fact that the cars/drivers in the sample are paired by collision. At first, however, an analysis is presented where the clustering (pairing) of study units is erroneously ignored.

Odds ratio estimation ignoring the clustering in the sample of accident-involved cars/drivers

If the clustering in the sample of accident-involved cars is not taken into account, every single accident-involved car (there are 2x3973=7946 such cars in the sample) is treated as an individual study unit. Since for every car the binary variables 'car make and model (A/B)' and 'car driver injury (yes/no)' have been recorded, we may generate from Table 1 Table 2 as 2x2 contingency table corresponding to an unmatched cohort study design.

From Table 2 one obtains the following driver injury risk estimates for car model A and car model B (group-specific absolute risks):

$\hat{r}\,(A)$ = 1322/4007 = 32.99% and
$\hat{r}\,(B)$ = 1269/3939 = 32.22%.

Thus, the estimated relative risk of drivers of car model B (subject car model) compared to car model A (reference car model) is given by

$$\hat{\lambda} = \hat{r}\,(B) \,/\, \hat{r}\,(A) = 0.9765.$$

Instead of the two group-specific risks one could calculate the corresponding group-specific driver

---

10 Car model B may not necessarily be a specific car model. Rather, it may also be interpreted as 'not car model A.

11 In this scheme the guilty party is referred to as car 1.

No.	Make and model		Driver injury		Relevance of subpopulation for matched analysis		Number of accidents in sample
	car 1	car 2	car 1	car 2	Matched cohort design	Matched case-control design	
1	A	A	yes	yes			137
2	A	A	yes	no		X	107
3	A	A	no	yes		X	368
4	A	A	no	no			548
5	A	B	yes	yes	X		114
6	A	B	yes	no	XX	XX	77
7	A	B	no	yes	XX	XX	273
8	A	B	no	no	X		427
9	B	A	yes	yes	X		76
10	B	A	yes	no	XX	XX	46
11	B	A	no	yes	XX	XX	306
12	B	A	no	no	X		368
13	B	B	yes	yes			152
14	B	B	yes	no		X	81
15	B	B	no	yes		X	375
16	B	B	no	no			518
Total							3973
Legend: X=subpopulation of concordant pairs (not relevant), XX=subpopulation of discordant pairs (relevant)							

Table 1: Empirical database of two-car accidents

Make and model of car	Car driver injured?		Total
	yes	no	
Model A ('other')	1322	2685	4007
Model B ('subject')	1269	2670	3939
Total	2591	5355	7946

Table 2: Crosstabulation ignoring the pairing of accident-involved cars/drivers

injury odds as well to obtain the estimated driver injury odds ratio (cross-product ratio), comparing car model B to car model A:

$$\hat{\psi} = (1269/2670) / (1322/2685) = 0.9653.$$

As can be seen, both the estimated relative risk and the odds ratio estimate are very close to unity. Thus, from an analysis ignoring clustering the conclusion would be drawn that the subject car model B has the same level of crashworthiness as the reference car model A.

Statistical calculations (based on a logarithmic transformation of the two measures of comparative chance to obtain a better approximation by the normal distribution) lead to the result that the population value of the relative risk and the odds ratio does not differ from unity. For instance, the 95% confidence interval for the odds ratio ranges from 0.8789 to 1.0603.

Clearly, the above analysis would be meaningful if the m=7946 cars in the sample were independently drawn from the population of all cars that are involved in two-car crashes (A/B, A/A and B/B crashes). This, however, is obviously not the case as always pairs of cars are drawn. Consequently, any methodologically sound analysis must explicitly observe that the database actually is a sample of n= 3973 pairs of cars. If clustering is properly taken into account, it appears that the passive safety levels of the two car models under consideration are by no means identical. Rather, the crashworthiness level of car model B is significantly higher than the corresponding safety level of car model A.

Matched pairs analysis without adjustment for concomitant variables

If every matched pair of accident-involved cars is treated as a single study unit, one can build from Table 1 for each of the two possible matched study designs the corresponding 2x2 contingency table which forms the basis of a matched analysis. It becomes evident that in contrast to the above (unmatched) analysis where all subpopulations of accidents were considered, only 8 out of the 16 subpopulations of accidents are relevant in a matched analysis.

Model B car driver injured?	Model A car driver injured?		Total
	yes	no	
yes	190	319	509
no	383	795	1178
Total	573	1114	1687

Table 3: Contingency table under the matched cohort study design (Design I)

Car model of injured driver	Car model of uninjured driver		Total
	Model B	Model A	
Model B	456	319	775
Model A	383	475	858
Total	839	794	1633

Table 4: Contingency table under the case-control study design (Design II)

Let as before car model B be the subject car model. Then, under the matched cohort study design (Design I) one obtains Table 3 2x2 table.

Under the matched case-control study design (Design II) with injured drivers as cases and uninjured drivers as controls, the 2x2 table looks like Table 4.

It appears, that under Design *i* the 2x2 table contains 1687 of the 3973 accidents (i.e. 42.5% of all crashes). Under Design II the table shows the 2-dimensional distribution of 1633 accidents (or 41.1% of all crashes). Obviously, as compared with an unmatched study of two-car accidents where every single accident-involved car (there are 2x3973=7946 such cars) is treated as an individual study unit, the concept of pairing leads to smaller numbers of observations.

Although the above contingency tables for Design *i* and Design II are not identical, exactly the same conclusions about the relative chance of driver injury can be drawn from the two tables. The main result is obtained by calculating the matched odds ratio, i.e. the estimate of the odds ratio in the case of paired data. According to a well-known theorem (sometimes called the fundamental theorem of epidemiology) the matched odds ratio takes on the same numerical value under both matched designs:

$$\hat{\psi}_m = 319 / 383 = 0.8329.$$

Since 1 – 0.8329=0.1671, the main conclusion is that being the driver of a model B car will reduce the chance of injury by approximately 17% compared to a model A car. As an appropriate statistical test (McNemar's test) shows, the null hypothesis of 'no association between car make and model and car driver injury' can be rejected at the 2 percent level.

Thus, it becomes evident that when pairing of accident-involved cars is properly taken into account the superiority of car model B compared to car model A is statistically proven. If pairing is erroneously ignored, one does not come to this conclusion. Obviously, the disregard of the multi-level data structure leads to biased vehicle crashworthiness assessment results.

Matched pairs analysis with adjustment for concomitant variables

In the case of paired car/driver data, the driver injury odds ratio can be adjusted for concomitant variables like gender of car driver and/or mass of opponent car by using fixed effects regression models. If, for instance, the driver's injury status (driver injured yes/no) is assumed to be a function of the car model driven and the driver's gender, one can estimate an appropriate fixed effects logistic regression model. As a result one obtains the 'gender-adjusted' driver injury odds ratio estimate for the subject car model compared to the reference car model. The fixed effects logistic regression model may also be used to adjust the driver injury odds ratio simultaneously for several concomitant variables (e.g. driver injury odds ratio adjusted for driver age and opponent vehicle mass). Similarly, more than two car model categories can be considered.

The fixed effects logit model has been applied to empirical two-car accident data from the German traffic accident statistics. In the results reported below driver injury status is a binary variable defined as 'severely injured or killed yes/no'. To keep the example simple, the risk factor car make and model was also considered to be a binary variable defined as 'Golf-3 yes/no'. The odds ratio for the risk factor has been estimated both without and with adjustment for confounding factors using the LOGISTIC procedure of the SAS system. To illustrate the application of the fixed effects logit model a vehicle characteristic (opponent car mass in kg) and a driver characteristic (driver gender) have been selected as covariates from a larger set of possible confounders. For details see [1].

Based on a sample of n=27250 two-car accidents where exactly one driver was injured (matched case-control design) the unadjusted odds ratio for covariate 'Golf-3 yes/no' was estimated at[12]

$$\hat{\psi}_m = 1246/1576 = 0.791$$

with 95 percent confidence limits 0.734 and 0.852 (so-called Wald confidence limits). This means that compared to other cars the driver injury odds for Golf-3 is about 21 percent lower (1–0.791=0.209). In view of this result Golf-3 can be assessed as 'significantly safer than other cars'.

As Table 5 shows, the estimated odds ratio for the risk factor car make and model decreases if in addition to car make and model other covariates are included in the fixed effects logit model. The difference between the unadjusted (regression model M1) and the adjusted odds ratio (regression models M2 and M3), however, is not statistically significant since the corresponding confidence intervals overlap.

The estimation results for the fixed effects logit model M3 yield an adjusted odds ratio for the risk factor of 0.707. This can be interpreted as follows: (i) given that the opponent car has the same mass as the Golf-3 and (ii) given that the two car drivers have the same gender, the chance of being injured is for Golf-3 drivers 29 percent lower (1–0.707= 0.293) than for drivers of other car models. In M3 the upper confidence interval limit (UCL) is far below unity (0.773). Therefore, the crash performance of the Golf-3 can be considered as significantly better than the performance of other car models. For each of the three regression models the confidence interval for the odds ratio related to the risk factor is given in Table 5. As the three confidence intervals overlap, the crashworthiness assessment of Golf-3 does not substantially change after adjustment for the factors 'driver gender' and 'mass of opponent car'.

There may, however, be covariates where the unadjusted and adjusted odds ratio differ significantly. Among other things Table 5 shows that the estimated odds ratio for the covariate 'driver gender' equals 0.480[13] if one only adjusts for car make and model (regression model M2), but is equal to 0.539 if, in addition, adjustment is made also for mass of opponent car (regression model M3). Looking at the confidence intervals it can be concluded that the adjusted odds ratio is different from the unadjusted. The absolute difference between the two values is, however, rather small (0.539–0.480=0.059). As driver gender and opponent car mass are largely independent determinants of driver injury status, this result is not surprising.

Fixed effects logit model of diver injury					
Model	Covariate(s)	Odds ratio for covariate			Relative length of CI[1)]
		LCL	Estimate	UCL	
M1	Golf-3 yes/no	.734	.791	.852	.149
M2	Golf-3 yes/no	.700	.756	.816	.153
	Male driver yes/no	.462	.480	.498	.075
M3	Golf-3 yes/no	.647	.707	.773	.178
	Male driver yes/no	.515	.539	.565	.093
	Mass of opponent car (100 kg)	1.277	1.289	1.302	.019

1) Relative length of confidence interval=(UCL–LCL)/Estimate

Table 5: Odds ratio estimates obtained from the fixed effects logit model

Finally, it should be noted that in the regression models M2 and M3 the coefficients and thus the odds ratios for the various determinants of driver injury status are estimated with quite different levels of accuracy. As the relative lengths of the confidence intervals (length of interval divided by midpoint of interval) show, the estimation of the coefficient for mass of opponent car is by far the most accurate. According to M3, it is almost certain (confidence level 95 percent) that colliding with a 'heavier' car rather than with a 'lighter' car (mass difference 100 kg) increases the driver's odds of being injured between 27.7 and 30.2 percent.

Alternative statistical models of driver injury for paired-by-collision car/driver data

In empirical crashworthiness studies where data on cars/drivers matched in pairs are to be analysed and where car driver injury status is the criterion variable of interest, the fixed effects logit model is certainly an appropriate statistical tool. This is because the model

- has a sound theoretical basis,
- is relatively easy to understand and to handle also for non-statisticians and
- can be estimated using standard statistical software.

12 In this example Golf-3 is compared with all other car models, not only with Golf-2 as was the case in the previous example.

13 Being a male driver reduces injury odds by 52% compared to female drivers.

As can be expected, however, various alternatives to the fixed effects logit model are available. The choice between these alternative models mainly depends on the scaling of the dependent variable car driver injury status. Subsequently, some of the candidate regression models are mentioned briefly without going into any methodological detail.

Driver injury status as a binary variable

When driver injury status is a binary variable (injury yes/no) random effects models of the logit and probit type can be considered as alternatives to the fixed effects logit model. See [4], p. 837-849, and [8], p. 62-70. Another alternative to be mentioned is the bivariate logit model with covariates describing not only the accident but also the two cars and drivers involved in the accident. This model was first proposed by [9]. It should be noted here that bivariate modelling approaches where only accident-specific (but no car- and driver-specific) covariates can be incorporated, are not really useful for crashworthiness assessment purposes. This is the reason why, for instance, the bivariate logit model derived from the log-linear model (see, for instance, [10], p. 223-225) is not suitable in our context.

Finally, the Bradley-Terry model developed for paired comparisons is another candidate modelling approach. See [4], p. 270-276, [11], p. 102-103, and [12]. In the SARAC 2 project this model has been applied to two-car accident data [13] .

Driver injury status as a variable with several ordered levels

When driver injury status is measured on an ordinal scale (e.g. uninjured, slightly injured, severely injured, killed or, alternatively, AIS 0 to 6) the fixed effects cumulative logit model can be applied to assess the role of the various car and driver characteristics as determinants of driver injury. For a software-oriented description see [8], p. 70-74.

As can be expected, the proper application of the various models mentioned above requires deeper knowledge of statistical theory and more specialised software.

References

1 H. HAUTZINGER: Design and Analysis of Matched Studies in Empirical Car Safety Research, Report S2-246, SARAC 2 project, Heilbronn/Germany, IVT, 2006

2 M. WOODWARD: Epidemiology – Study Design and Data Analysis, Boca Raton/ London/New York/Washington DC, Chapman & Hall/CRC, 1999

3 H. GOLDSTEIN: Multilevel Statistical Models, 2nd edn., London, Arnold, 1995

4 W.G. GREENE: Econometric Analysis, 4th edn., Upper Saddle River, NJ, Prentice Hall, 2000

5 H. HAUTZINGER, D. HEIDEMANN: Econometric Analysis of the German Mobility Panel, in Travel Behaviour Research – The Leading Edge (ed. D HENSHER), London, Pergamon, 2000, p. 481-499

6 H. HAUTZINGER: Description and Analysis of Existing Car Safety Rating Methods, Report of Sub-Task 1.1 of SARAC 1 project, Heilbronn/Germany, IVT, 2001

7 J.-L. MARTIN, Y. DERRIEN, B. LAUMON: Estimating relative driver fatality and injury risk according to some characteristics of cars and drivers using matched-pair multivariate analysis, Paper presented at the ESV Conference 2003

8 P.D. ALLISON: Fixed Effects Regression Methods for Longitudinal Data Using SAS, Cary, NC, SAS Institute Inc., 2005

9 D.R. COX: The Analysis of Multivariate Binary Data, Applied Statistics (Journal of the Royal Statitistical Society, Series C), 21 (2), 1972, p. 113-120

10 P. McCULLAGH, J.A. NELDER: Generalized Linear Models, 2nd edn., London, Chapman & Hall, 1992

11 D.R. COX: Analysis of Binary Data, London, Chapman & Hall, 1970

12 D.R. HUNTER: MM Algorithms for Generalized Bradley-Terry Models, The Annals of Statistics, 32 (1), 2004, p. 384-406

13 C. PASTOR: Correlation of NCAP Star Rating and German Accident Data Using Methods of ‘Paired Comparisons’, internal paper, SARAC 2 project, Bergisch Gladbach, BASt, 2004

M. Pfeiffer, J. Schmidt
Institute of Applied Transport and Tourism Research (IVT), Mannheim, Germany

Statistical and Methodological Foundations of the GIDAS Accident Survey System

Abstract

In Germany, in-depth accident investigations are carried out in the Hannover area since 1973. In 1999 a second region was added with surveys in Dresden and the surrounding area. Internationally, the acronym GIDAS (German In-Depth Accident Study) is commonly used for these surveys. Compared to many other countries, the sample sizes of the GIDAS surveys are much larger. The goal is to collect 1.000 accidents involving personal injuries per year and region.

Data collection takes place by using a sampling procedure, which can be interpreted as a two-stage process with time intervals as primary units and accidents as secondary units. An important question is, to what extend these samples are representative for the target population from which they are drawn. Analyses show, for example, that accidents with persons killed or seriously injured are overrepresented in the samples compared to accidents with slightly injured persons. This means, that these data are subject to biases due to uncontrolled variation of sample inclusion probability. Therefore, appropriate weighting and expansion methods have to be applied in order to adjust or correct for these biases.

The contribution describes the statistical and methodological principles underlying the GIDAS surveys with respect to sampling procedure, data collection and expansion. In addition, some suggestions regarding potential improvements of study design are made from a methodological point of view.

Introduction

In-depth accident investigations represent an important basis for empirical traffic safety research. At national and international level various analyses and comparisons are carried out on the basis of “in-depth data”. These data play a decisive role for example within the validation of EuroNCAP results on secondary safety of individual passenger car models. Consequently, statistically sound methods of data analysis and population parameter estimation are of high importance.

In Germany, in-depth accident investigations are carried out in the Hannover area since 1973. In 1999 a second region was added with surveys in Dresden and the surrounding area. Internationally, the acronym GIDAS (German In-Depth Accident Study) is commonly used for these surveys. Compared to many other countries, the sample sizes of the GIDAS surveys are much larger. Moreover, data collection takes place by using a sampling procedure, which can be interpreted as a two-stage process with time intervals as primary units and accidents as secondary units.

The contribution describes the statistical and methodological principles of the GIDAS survey system with respect to sampling procedure, data collection and expansion. By the end of last year IVT finished a research project on behalf of BASt which was dealing with examining and adjusting the previous weighting and expansion methods for the two regional accident investigations, using data from the years 2000 and 2001 [1].

Finally, some suggestions regarding potential improvements of study design are made from a methodological point of view.

The Project GIDAS: In-Depth Investigation on Scene in the Hannover and Dresden Areas

Investigation methodology

One of the main characteristics of in-depth accident investigations is that the research team arrives on scene and starts collecting the accident data immediately after having been alarmed by the police, rescue services, or fire department headquarters (“on scene” and “in time”). Apart from the acquisition of accident data on site (gathering information, taking pictures, etc.), the process of data collection also covers additional phases like the interrogation of witnesses or the collection of data at different places (e.g. hospitals, scrap yards). Basically, in-depth data can also be collected exclusively in retrospect by ex post examination of

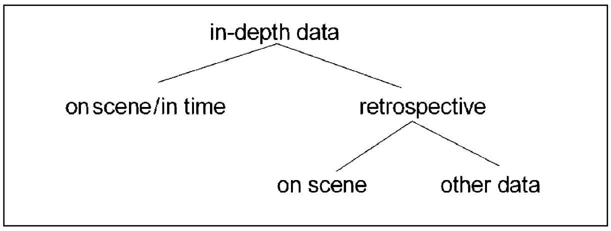


Figure 1: Categorisation of in-depth data on road traffic accidents

the spot of accident ("on scene") or by gathering relevant data solely at other places.

Accident investigation in the Hannover and Dresden areas takes place daily during two six-hour time intervals (so-called shifts) following a 2-week cycle. During the first week data collection is carried out from 12:00 a.m. to 06:00 a.m. and from 12:00 p.m. to 06:00 p.m. and within the second week those accidents are documented that occur during the other two intervals. So, the premise for the acquisition of accident data is that the accident occurs within the respective time interval and within the demarcated investigation area. In any case, however, only accidents involving personal injury are taken into consideration.

Within the shifts, the first reported accident involving personal injury is recorded by the team and subsequently all other accidents. Due to the fact that data acquisition on scene takes about one hour per accident, overlapping of accidents is possible. In this case, the most current accident after reestablishment of the operational readiness of the team is registered.

Each research team consists of two technicians, a physician and a co-ordinator and has two vehicles at its disposal. While the technician's vehicle remains at the scene of accident, the physician's vehicle, if necessary, accompanies injured persons to the hospital.

The goal is to collect 1.000 accidents involving personal injuries per year and region. For each accident hundreds of variables are recorded covering data on accident situation (for example traffic regulation), involved vehicles and persons, as well as information on vehicle deformation and injury patterns. Moreover, an accident reconstruction takes place.

GIDAS survey plan from a sampling point of view

Target population and Ample

Concerning the sampling procedure, the target population of the GIDAS sample consists of all police-recorded accidents involving personal injuries which occur in the Hannover and Dresden areas. Accidents which are reported neither to police nor to the rescue services do, strictly speaking, not belong to the target population, since they are not included in the official accident statistics and, therefore, cannot be considered in the expansion factor.

The sampling units – that means the accidents – can be seen as "events" occurring in time and space. For this reason, at the beginning of the survey period there is no list containing all elements of the target population which could serve as a sampling frame. Moreover, neither the annual sample size nor the size of the target population is known in advance.

Selection of time clusters as primary units

Since the 1st of August 1984 the "in-depth investigations on scene" in the Hannover area have been carried out according to a sampling plan developed by HAUTZINGER [2] in the context of a research project on behalf of BASt. This sampling plan corresponds to a two-stage selection procedure. The first stage is to randomly select time intervals as primary units. Here, the primary units correspond to time clusters of accidents. Due to organisational reasons, for each calendar week two basic types of survey intervals exist.

Type A: where data collection is carried out daily between 12:00 a.m. and 06:00 a.m. and between 12:00 p.m. and 06:00 p.m.

Type B: where all accidents are documented which occur between 06:00 a.m. and 12:00 p.m. and between 06:00 p.m. and 12:00 a.m.

Over the year, the time clusters according to the two basic types are selected alternately, that means, first week type A, second week type B, third week Type A, fourth week type B and so on. Thus, the selection of primary units can be regarded as a systematic sample with sampling interval 2:

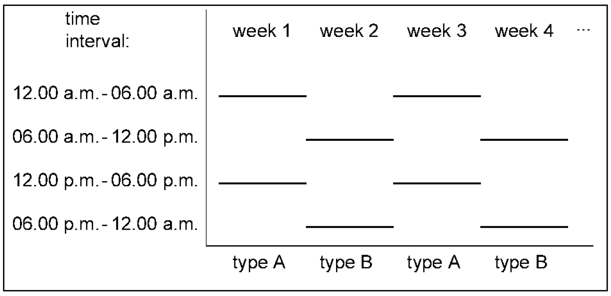


Figure 2: Systematic selection of time intervals

Due to this procedure all parts of the year are equally covered by the sample. So, with respect to the selection of primary units, this systematic sampling is even superior to simple random sampling of time intervals.

Assuming perfect preconditions, this means that within each selected time interval all police-recorded accidents are reported to the investigation team and all reported accidents are documented by the team, this selection of time intervals would be absolutely sufficient. But these ideal preconditions are not given in practice: on the one hand not all police-recorded accidents are reported to the research team and on the other hand not every reported accident can be documented by the team. Therefore, a sampling procedure at the second stage, this means for the selection of accidents within the selected time intervals, is needed.

Selection of accidents as secondary units

With regard to selection at the second stage, special emphasis has to be given to the documentation of as many accidents as possible. For this reason the first reported accident of a selected time cluster has to be documented and after that all other reported accidents as far as the team is ready for operation. In the case of overlapping of accidents, the most current accident after reestablishment of the operational readiness is documented.

From a statistical point of view, inclusion in the sample depends on the results of two subsequent random experiments. On the basis of a first random experiment it is determined whether or not a police-recorded accident is reported to the survey team. In case of an incoming report a second random experiment determines whether or not an accident will be registered by the team. The accident will be documented either if at the corresponding point in time the team is ready for operation or if the

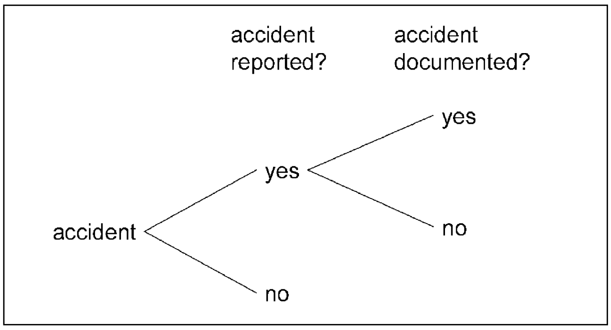


Figure 3: Selection of accidents

reported accident is the most recent reported accident after reestablishment of operational readiness of the team.

An important question is, to what extent these samples are representative for the target population from which they are drawn. Representative means, that the obtained results can be generalised from the sample to the population which normally consists of all injury accidents in the study region. Even if the in-depth study is based on a well specified random sampling scheme the empirical data actually collected might be biased. Analyses of GIDAS data show, for example, that accidents with persons killed or seriously injured are overrepresented in the sample compared to accidents with slightly injured persons. For in-depth studies which, unlike GIDAS, are not built upon a proper sampling plan, the biases due to uncontrolled variation of sample inclusion probability might be even more severe. In several European in-depth studies purposive rather than random selection of accidents takes place.

Selection probabilities

If we assume for the moment that accident severity is the only determining factor for the reporting or non-reporting of an accident, the reporting rates shown in the first column of Table 1 are obtained.

In contrast to accidents with slightly injured persons, accidents with seriously injured persons or persons killed are significantly more frequently reported to the investigation team. Of course, a reporting rate of 100 percent within each category would be ideal.

The next column shows, to which extent the reported accidents are actually documented. The percentages vary between 85 and 96 percent; the ideal case would be given if these rates were identical.

	percentage reported	percentage documented	selection probability (%)
accident with slightly injured persons	34.3	84.5	29.0
accident with seriously injured persons	66.3	88.4	58.6
accident with persons killed	75.0	96.3	72.2

Table 1: Selection probabilities (Hannover area, year 2000) [3]

The third column finally shows the resulting selection probabilities. While an accident with slightly injured persons is selected with a probability of about 30%, the inclusion probability for an accident with persons killed amounts to more than 70%.

These analyses show that the raw GIDAS sample is subject to biases due to uncontrolled variation of sample inclusion probability – at least with respect to accident severity. Due to small sample sizes or imperfect data collection procedures, in-depth traffic accident data are often susceptible to a lack of representativeness with respect to the underlying target population. Taking this into account, an appropriate weighting procedure is needed for in-depth data in order to remove these biases as far as possible. The variables to be used for this weighting process must, of course, be available in the official accident data files and should be correlated highly with as many as possible "true" in-depth accident characteristics. By adjusting the sample joint distribution of certain structural variables (e.g. road type and accident outcome severity) to the corresponding distribution in the population of all accidents as recorded in national statistics, the accuracy of estimates referring to the true in-depth variables (e.g. collision speed) can be improved.

Weighting and Expansion

Previous weighting procedure

At present, the GIDAS weighting procedure is based on the characteristics

- severity of accident (accident with slightly injured persons, with seriously injured persons, with persons killed),
- locality of accident (within built-up areas, outside built-up areas) and
- time interval of accident occurrence (12:00 a.m. –06:00 a.m./06:00 a.m.–12:00 p.m./12:00 p.m. –06:00 p.m./06:00 p.m.–12:00 a.m.).

The weighting procedure consists of an adjustment of the three-dimensional sample contingency table to the corresponding table for the target population from official accident statistics.

Alternative weighting methods

Within a project on expanding GIDAS data to the regional and national level IVT developed and tested alternative methods for the expansion of the Hannover sample to the Hannover area and to Germany, for the expansion of the Dresden sample to the Dresden area and to Germany, and for the expansion of the pooled sample (Hannover plus Dresden) to Germany.

There are several alternatives to carry out such weighting and expansions procedures, among them two-stage and hierarchical methods:

Two-stage procedures. As mentioned before, the in-depth investigations in the Hannover and Dresden areas are based on a two-stage sampling process. According to the principles of sampling theory, it would be most natural to use a two-stage expansion methodology. Here, in a first step the secondary units (accidents) have to be expanded to the primary units (parts of calendar weeks) and after that the expansion of the primary units takes place.

Hierarchical methods. The principle underlying hierarchical weighting procedures is also an adjustment of multi-dimensional tables to the corresponding tables from official accident statistics. However, due to restrictions with respect to the number of cases, a certain weighting variable is adjusted only within selected categories of another weighting variable.

Hierarchical weighting procedure

For example, for the regional expansion of the GIDAS data 2000 and 2001 a hierarchical weighting procedure was developed which is based on the variables

- severity of accident (accident with slightly injured persons, with seriously injured persons, with persons killed) and

- time interval of accident occurrence (as before)
- and kind of accident.

It was assumed that locality of accident is strongly correlated to accident severity and, therefore, using one of them in the weighting procedure might be sufficient. Moreover, it was hoped that considering the variable "kind of accident" in the weighting process will compensate possible biases which are due to the fact that the process of data collection takes longer for accidents with a relatively large number of road users involved, which in turn might lead to an overrepresentation of these accidents. Here, the new variable kind of accident is considered only in connection with accidents with slightly injured persons.

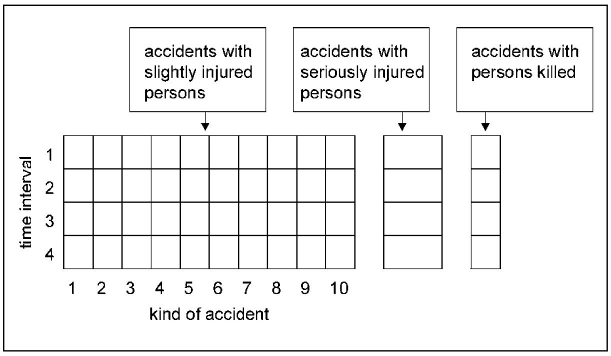


Figure 4: Hierarchical weighting scheme

The weighting procedure can be illustrated by the Figure 4.

Accidents with slightly injured persons are further subdivided by time interval and kind of accident, whereas accidents with seriously injured persons or persons killed are subdivided only by time interval.

Results: expansion of Hannover data 2000 and 2001 to the regional level

Table 2 summarises the results of a regional expansion of the Hannover data 2000 and 2001. The figures in the table represent measures of the goodness-of-fit of weighted distributions for several accident criteria resulting from different expansion methods. On the basis of data from the year 2000

variable	2000				2001			
	unweighted distr.	previous weighting method	2-stage weighting method	hierarchical method	unweighted distr.	previous weighting method	2-stage weighting method	hierarchical method
	Goodness-of-fit measure V							
severity of acc.	0,35	0,01*	0*	0*	0,29	0*	0*	0*
time interval	0,16	0,01*	0*	0,01*	0,09	0*	0*	0,02*
locality	0,07	0*	0*	0	0,13	0*	0*	0,06
kind of accident	0,32	0,28	0,26	0,03*	0,28	0,24	0,25	0,02*
number of road users involved	0,10	0,08	0,06	0,11	0,12	0,07	0,05	0,15
light conditions	0,03	0,05	0,06	0,06	0,05	0,02	0,05	0,01
road class	0,17	0,13	0,14	0,11	-	-	-	-
type of acident	0,38	0,34	0,35	0,30	-	-	-	-
influence of alcohol	0,07	0,06	0,05	0,07	0,02	0	0,03	0,02
obstacles next to carriageway	-	-	-	-	0,20	0,14	0,14	0,11
age group	0,10	0,11	0,10	0,08	-	-	-	-
gender	0,04	0,04	0,03	0,01	-	-	-	-
holding period of driving license	0,04	0,05	0,07	0,06	-	-	-	-
injury severity	0,23	0,07	0,06	0,05	-	-	-	-
transport mode	0,15	0,14	0,17	0,14	-	-	-	-
total	2,21	1,37	1,35	1,03	1,18	0,47	0,52	0,39
total without weighting var.	1,31	1,07	1,09	0,99	0,39	0,23	0,27	0,29
* weighting variable								

Table 2: Goodness-of-fit of weighted distributions for several accident criteria resulting from different expansion methods (regional expansion of Hannover data 2000 and 2001)

analyses have also been carried out at the level of road users involved. The goodness-of-fit measure V is based on chi-square ($V = \sqrt{\chi^2 / n}$); the lower the value, the better the fit of the distribution compared to the one from official accident statistics.

The table shows that appropriate expansion and weighting procedures can substantially improve the accuracy of data from in-depth investigations (for example road class or injury severity). However we did not succeed in finding a weighting scheme where it was possible to simultaneously improve the accuracy of all variables under consideration. In connection with the two-stage expansion method it was found that the theoretical advantages of this method compared to the simple weighting procedure are relatively small, especially, if one takes into account the complexity of the calculation process necessary to obtain the corresponding expansion factors.

Of course, the main objective of expanding in-depth data to the target population is to expand variables which are not included in the official accident statistics (e.g. AIS, EES, etc.). Here, variables which are contained both in the sample and in the official statistics have been analysed in order to check the goodness-of-fit of the weighted sample distributions.

Potential Improvements of Study Design

The results of the expansion show that even with alternative, mostly hierarchical weighting procedures it is not possible to adjust all variables for which the distributions from official accident statistics are known with sufficient accuracy to the basic population. So it can be expected that the same occurs when expanding true in-depth variables like collision speed, for example. As a consequence, at least for research topics of particular importance it is recommended to develop an individual, i.e. variable-specific weighting scheme for the respective accident characteristic under investigation.

Usually, accident characteristics which are recorded by police are also collected by the in-depth investigation team. However, it might well be that these two different measurements do not yield the same results, e.g. if police assigns an accident to another kind of accident than the research team does. It is important to say that in any case the police recorded data (standard traffic accident reports) of the accidents in the sample have to be used for expansion purposes. Even if the data from the in-depth investigation team are more precise it would not be correct to base the weighting factors on them, because in this case some of the accidents in the sample would be assigned to the wrong stratum (according to the target population).

With respect to expansion it is therefore inevitable to add the complete catalogue of variables of the standard traffic accident report to each documented accident. However, partially the problem exists that there are some discrepancies between the standard traffic accident report filled in by police and the official database, which are due to plausibility checks and data adjustment. Thus, here also the problem appears that according to the standard traffic accident report some accidents are assigned to another stratum than according to the official database. From a methodological point of view it would be favourable if the standard traffic accident reports in the Hannover and Dresden area would be supplemented by the GIDAS case number as far as the accident has been documented by the GIDAS team. This would make it possible to merge the in-depth data with the police-recorded data by case number of accident.

Finally, there are several possibilities to improve the current sampling and data collection procedure in order to obtain representative results. For example, in time intervals with high accident intensity one could work with two teams in parallel in order to be able to collect all accidents reported within the shift. In this case the sampling procedure would be closer to a one-stage cluster sampling which from a methodological point of view has some advantages compared to the present two-stage procedure.

Alternatively at least the fatal accidents could be completely collected in retrospect. I.e., fatal accidents which are not reported to the team or could not be documented during the shift would as far as possible be collected retrospectively. This could even be extended to accidents which do not occur during the selected time intervals.

Lastly, it is advisable to co-ordinate the surveys in the Hannover and Dresden area regarding the teams' operation intervals. I.e., that the two daily shifts should not run in parallel. Rather, if the Hannover team covers the shifts 12:00 a.m. to 06:00 a.m. to 12:00 p.m. and 06:00 p.m. the Dresden team should cover the shifts 06:00 a.m. to 12:00 p.m. and 06:00 p.m. to 12:00 a.m. so that across the two areas all four types of selection intervals occur with the same frequency in each week of the year. This procedure would particularly be favourable with respect to the national expansion of GIDAS data.

References

[1] H. HAUTZINGER, M. PFEIFFER, J. SCHMIDT: Hochrechnung von Daten aus Erhebungen am Unfallort. Schlussbericht zum Forschungsprojekt FE 82.22 1/2002 der Bundesanstalt für Straßenwesen. Mannheim, IVT, 2005

[2] H. HAUTZINGER: Stichproben- und Hochrechnungsverfahren für Verkehrssicherheitsuntersuchungen. Forschungsberichte der Bundesanstalt für Straßenwesen, Bereich Unfallforschung, Heft 111. Bergisch Gladbach, BASt, 1985

[3] D. OTTE & J. NEHMZOW: Jahresbericht zur Unfallerhebung und Gewichtung 2000. Hannover, MHH, 2003

J. Gail, U. Ellmers
Bundesanstalt für Straßenwesen,
Bergisch Gladbach, Germany

Active Vehicle Safety Studies Based on In-Depth Accident Investigations – Possible or not?

Abstract

Since 2005 the German In-Depth Accident Study (GIDAS) also records aspects of active vehicle safety. This is done because vehicles are fitted with an increasing number of active safety devices which have undoubtedly an influence on the number, severity and course of accidents. Accident researchers expect that collecting active safety data will facilitate to assess and quantify the impact of these and future devices. It is the aim of this paper to outline benefits and limitations associated with the recording of active safety aspects within in-depth studies.

An overview about possible areas where active safety data can be useful will be given. For that purpose single safety or comfort systems will be selected to estimate the effects of an accident database which includes variables associated with these systems.

Questions with regard to the limitations of collecting active safety data will be addressed. Possible items are for example the usability of the data recorded, the real accident cause, the small number of relevant accidents, the time span needed to gather a sufficient dataset, the small share of vehicles equipped with a certain system or different functionalities of systems that are supposed to fall in the same category.

As a result user needs for a reasonable data collection of active safety elements will be elaborated.

Introduction

In 1973 German In-Depth Accident Studies were started at the Medical University Hannover on behalf of the Federal Highway Research Institute (BASt) to establish a database containing accident data. This database should help to support research analysing accident causations and thus improving passive vehicle safety, rescue or road infrastructure design. In the last years vehicles are fitted more and more with active safety systems like e.g. anti-lock braking systems (ABS), traction control or vehicle stability control (VSC) which are designed to enhance vehicle dynamics and to avoid accidents. Especially for VSC several studies show the positive impact of the system on accident statistics, e.g. see [1-6]. This development leads to the decision to record aspects of active vehicle safety in the German In-Depth Accident Study (GIDAS) as well. The data collection was started with the year 2005. Features like e.g. seat-belt reminder, park distance control or cruise control are included now. On the one hand it is recorded if the vehicle is fitted with some of these devices, on the other hand it is recorded how sophisticated the system is or which kind of functionality the system offers. It is the aim to be able to assess the positive or negative impact on traffic safety associated with these devices after several years of data collection.

Since active safety systems are developed to avoid accidents it seems to be an antagonism to detect effects in in-depth accident studies. Accidents which are avoided by these systems will not take place and thus will not appear in the database. However it might be possible to elaborate cases in which a certain vehicle segment is equipped with a safety device and a second comparable segment is not. Such a situation would allow to check if the segment of vehicles not being equipped is to a higher extent involved in special classes of accidents than the vehicles being equipped.

In the following sections the possibilities of collecting active safety data will be outlined. But also issues which limit the usability of in-depth studies recording variables of active safety will be taken into account.

Attributes of Active Safety

In a special record GIDAS collects the information of about 80 safety aspects associated with active safety. These systems address among others driving stability, braking performance, tyres visibility, lighting or ergonomics.

Some examples of active safety systems being recorded in GIDAS are:

- Cruise Control/Adaptive Cruise Control.

- Lane Keeping Assist/Lane Change Assist.
- Mirrors.
- Daytime Running Light.
- Advanced Frontlighting Sytems.
- Night Vision.
- Intelligent Stop Signal.
- Run-Flat Tyres.
- Brake Assist.
- Seat-belt Reminder.

The last example “Seat-belt Reminder” which in its effect actually is part of the passive safety is recorded together with active safety devices because wearing or not wearing a seat-belt is a decision taken far before an accident happens.

Also the function and operation of communication systems and comfort systems which enhance or at least influence the condition of the driver are part of the active safety record. It is for example checked how the phone or the navigation system can be operated, if a voice control is there, how the gear shift can be operated or where the buttons and switches for the engine brake or the distance control system are etc.

Some of the active safety systems can be found together with the primary information of the vehicle in another record of the GIDAS database. This is the case for technical failures, vehicle stability control systems or anti-lock braking systems. Information about active safety features is also available via the recorded questioning of the drivers or other participants of the accident. There it is asked how the reaction of the driver was with regard to steering or braking, how the visibility conditions were and what was done or operated before and during the course of the accident and why. The questioning comprises also if the driver has knowledge about certain safety features like ABS or brake assist which his vehicle is fitted with. The driver also should state if he had got some feedback from operating safety systems.

The GIDAS Codebook [10] yields a detailed listing of all active safety variables being recorded.

Examples

For each of the active safety variables a certain value is recorded in GIDAS indicating if the vehicle was equipped and – if yes – representing system properties.

In the following some examples of the values for four single safety systems are presented. In addition the number of vehicles equipped with the system in the GIDAS database 2005 is given in brackets. This number allows to get an impression how often certain active safety systems can be found in traffic and also in accident data. At the same time one can estimate if it is worth to evaluate the database with regard to a special safety device or if it is needed to wait for several further years of data collection. In total 1268 vehicles were involved in the accidents stored.

The variable “seat-belt reminder” can get the values:

0) not applicable	(214)
1) yes (without add. info)	(38)
2) no	(677)
3) only driver	(18)
4) driver and front pass.	(40)
5) first and second row	(1)
8) others	(0)
9) unknown	(155)

That means only 97 vehicles had a seat-belt reminder for at least one seat.

The variable “daytime running light” can get the values:

0) not applicable	(83)
1) yes (without add. info)	(68)
2) no	(858)
3) mandatory	(12)
4) switched on manually	(63)
8) others	(1)
9) unknown	(61)

Thus 144 vehicles drove with daytime running light.

The variable “run flat tires” can get the values:

0) not applicable	(80)
1) yes (without add. info)	(1)
2) no	(949)
3) with support ring	(0)
4) reinforced side wall	(0)

5) repair kit (1)

8) others (0)

9) unknown (115)

The result shows that one vehicle was equipped with run flat tires and for one vehicle a tire kit was used. Although all vehicle models of several series of one German car manufacturer are fitted with run flat tires standardly for more than one year nearly no relevant vehicle can be found in the database.

The variable “bend lighting” can get the values:

0) not applicable (117)

1) yes (without add. info) (1)

2) no (991)

8) others (0)

9) unknown (37)

Also the bend lighting is recorded only in one accident although some premium class cars can be purchased with the system. But here the problem is not the equipment rate alone but it might also be difficult to detect if the headlights comprise a swivelling mechanism.

In Figure 1 for a selection of the active safety variables the number of vehicles equipped with a device is illustrated for the GIDAS dataset of the year 2005.

The result shows that some safety or comfort devices like right mirrors, phone or cruise control occur frequently in the dataset promising successful future evaluations of the GIDAS database with regard to active vehicle safety. However, even when the figures are high they do not tell anything about the cause of the accident or if the safety system had any influence on it.

Other systems like collision mitigation or collision warning do not appear in the dataset. Either only few vehicles are equipped with these (sometimes expensive) systems up to now or the systems are not available because research and product development have not finished yet.

Benefits of Recording Active Safety Data

To collect active safety data within in-depth accident studies is based on expectations that the data will be suitable to show the impact of any safety, comfort or communication device on traffic safety, either positive or negative. To know these impact will enable researchers or policy makers to carry out cost-benefit assessments for the introduction of safety measures and to take corresponding actions. The latter was done in the past mainly for passive safety devices like seat-belts or airbags. Now the

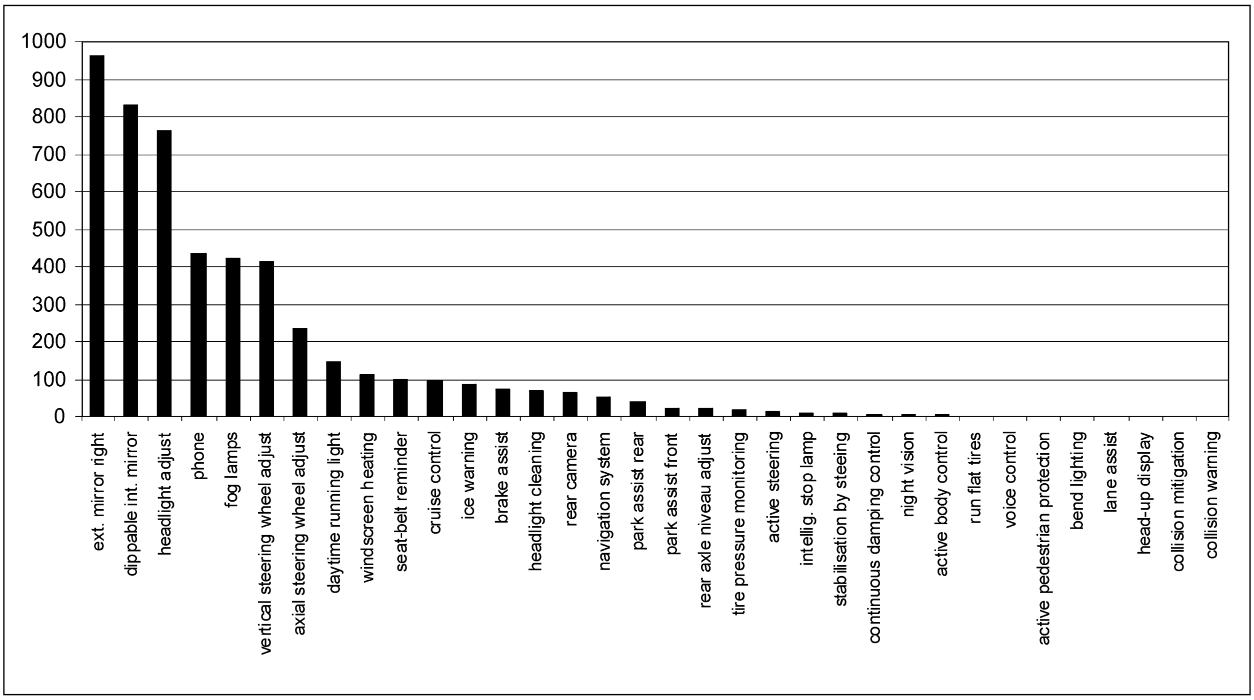


Figure 1: Number of selected active safety devices recorded in GIDAS 2005; in total 1268 vehicles were involved in the accidents stored

analyses should be extended to measures concerning longitudinal and lateral control of vehicle dynamics, vision, conspicuity or ergonomics. Knowledge about the real safety benefits will on the one hand help to optimise the systems and on the other hand to support legislation.

Researchers in the area of vehicle safety therefore hope to be able to answer questions like e.g.:

- In how far does Adaptive Cruise Control reduce (severity of) rear end accidents?
- What is the influence of lane keeping or lane change assist on accidents with vehicles in the adjacent lane?
- Does a head-up display reduce accidents due to eye distraction?

The importance of gaining information about active safety will increase in the next years since progress in vehicle safety will more rely on accident avoiding systems rather than on classical passive safety measures.

Examples

To outline what might be possible in future we did a preliminary check of the database with regard to the right exterior mirror. Since the data basis for active safety is still small, as was shown above, first evaluations would not yield usable results for systems with low equipment rate. Thus the right mirror was selected because most of the vehicles are fitted with it. The right mirror should have an influence on accidents with vehicles driving parallel in the same direction (German accident type 6 and kind of accident 3). 325 accidents were of this type and kind. But only one of these accidents was caused by a vehicle without a right mirror. Fortunately this accident dataset involved comments on the course of the accident which revealed that the accident happened between two bicycles.

How the evaluation of accident data with regard to active safety could work successfully is demonstrated by means of four examples. The first one was elaborated by BASt (Federal Highway Research Institute). The others were taken from literature.

Improved lighting

The first case addresses a safety device being part of the vehicle's lighting. It was examined by BASt using the national accident statistics of Germany. The active safety device which is dealt with here is anonymised to avoid conclusions with regard to the manufacturer.

To analyse the effectiveness of the device changes in accident numbers before and after introduction of the device are examined. Accidents which might be influenced by the safety system (relevant accidents) are the focus group for the analysis. To assess changes in accident numbers it is necessary to have a comparison group which should have a similar structure as the focus group. This guarantees to be able to eliminate effects which change accident numbers but are not due to the safety device. The ideal case is that the safety device only affects accidents of the focus group and not of the comparison group.

In the study on hand only accidents with vehicles which got their first registration in the same year are regarded. In year 1 of the study no vehicle was equipped with the system. In year 2 some of the vehicles were equipped with the system.

The focus group comprises relevant accidents with vehicle types which were equipped with the system in year 2 and accidents with the same vehicle types (being not equipped since the device was not available) in year 1.

The comparison group comprises all other accidents in year 1 and year 2 with the vehicle types mentioned above.

Table 1 gives an overview about the four groups of accidents taken into account and the associated accident numbers.

Whether the active safety system is effective can be seen by comparing the ratios of accident numbers between relevant and other accidents. This ratio

	vehicle types fitted with the safety device in year 2	
	year 1	year2
focus group (relevant accidents)	n11=63	n12=94
comparison group (other accidents)	n21=455	n22=617

Table 1: Accident numbers before and after the introduction of an active safety device

should have become smaller in year 2 if there is an improvement due to the safety device. For the system examined here this is not the case: the ratio is 0.15 in year 2 and 0.14 in year 1. So it was not possible to demonstrate the benefit of the safety system. However, the result is not significant (on a 5% level) so that a positive impact of the safety device cannot be excluded on the basis of the existing accident numbers. This also holds for a negative impact which however is highly not assumed to occur.

There are several reasons why it was not possible to elaborate significant statements. In year 2 about 400,000 accidents with personal injuries or severe property damage were recorded. But only 94 accidents were relevant for the safety device. With this amount of data significance for the effectiveness of the safety system would have been achieved if the focus group developed 35% better than the comparison group. Another problem is that the national accident statistics only contains accidents with personal injuries or severe property damage and a big amount of accidents with only light damages is not included and could therefore not be analysed.

So an effectiveness of the safety device could not be proven and not be excluded. But on principle national accident statistic as well as in-depth studies are suitable to be applied to active safety systems. This statement is strongly supported by the next two examples.

ESP effectiveness

With the same method as described above Y. Page and S. CUNY [9] determined the effectiveness of ESP (electronic stability program) on French roads. They looked at ESP relevant accidents involving cars of the type Renault Laguna and calculated an effectiveness of ESP of 43%. In the calculation they also took confounders like driver age and gender, vehicle age, pavement status and year of accident into account. However it was assumed that other safety systems introduced at the same time like tire pressure monitoring systems did not influence the accidents considered and thus did not bias the result. To avoid a bias effect due to emergency brake assist an accident subset was selected for which braking did not apply.

GRÖMPING et al. [7] used the example ESP to show how to determine the safety impact of a rarely fitted system on accident risk. Using GIDAS data they calculated that 44.13% of loss of stability accidents among non-ESP vehicles could be avoided if all these vehicles were equipped with ESP. Taking covariates like driver age, weather or time of the day into account they were able to elaborate the influence of ESP for different scenarios. E.g. for a young driver with a car with worn tires on a rainy night ESP has an estimated accident avoidance potential of 35.6%. For a 60 years old driver with new tires on a dry day ESP has an accident avoidance potential of only 12.5%.

Brake assisting system in pedestrian accidents

In [8] L. HANNAWALD has outlined a method how to estimate the potential of primary and secondary safety measures. The method was exemplarily shown for the active safety system “brake assist” (BAS) in pedestrian accidents. Injury risk functions were calculated using logistic regression depending on the collision speed. Since the GIDAS (German In-Depth Accident Study) database includes initial speed, mean braking deceleration and the real collision speed derived from accident reconstruction it was possible to determine the benefit of BAS for the reduction of fatalities and injuries of pedestrians.

Brake assisting system and automatic emergency braking

BUSCH et al. [11] describe a method how to calculate prognoses of the safety benefit of accident avoiding systems on the basis of in-depth studies. They used data of GIDAS together with a computer simulation for the courses of the single accidents to estimate the impact of BAS and automatic emergency braking. The probabilities for injuries depending on the delta-v of the collisions are calculated with and without the safety system. The difference of the probabilities representing the safety gain of the system for one accident then is used to estimate the total safety benefit of the active safety measure by means of the national accident statistics.

As result the widespread use of BAS would reduce road traffic fatalities in Germany of about 3% and severe injuries of about 4%. The benefits are not only related to the passengers of motor vehicles but are especially high for bicyclists and pedestrians.

For a combination of BAS with an automatic emergency braking the estimated benefits are a reduction of both fatalities and severe injuries of about 6%.

Limitations

The possibility to benefit from collecting active safety data while analysing accidents at the roadside depends on the usability of the data recorded. A general and obvious prerequisite is that the physical figures and facts are ascertained correctly and the questions to the participants are answered truly.

Since active safety devices are entering the market at the moment the equipment rates of vehicles are still small. As a consequence one will not find these systems in many vehicles involved in the accidents of the database. Additionally in in-depth accident studies it is only feasible to record a limited number of accidents per year so that the probability to find an accident which includes a vehicle with the active safety system is small. Even more rarely will be the case that the safety device would have had an essential influence on the course of the accident.

That means that the time span to gather a sufficient dataset will be at least several years or even up to ten years. Evaluations carried out too early face the risk to detect short term effects of the active safety system only. More likely is the situation that the number of relevant accidents is so small that significance can scarcely be achieved (see example with regard to lighting given above).

For the assessment of the impact of many of the active safety features it is necessary to know the accident causation. The real reasons of an accident are mostly found out by reconstructing the course of the accident. This makes it possible to gain insight into the mechanisms behind and allows to interpret the calculated effects of a safety system. The importance of accident reconstruction especially for active safety is illustrated by the example with the brake assist [8].

Another issue that has to be considered in this context is that the safety systems might work different in similar but not equal situations. This will be the case with collision mitigation or collision avoidance systems which also take data from environment like detection of obstacles into account. Equal objects that have to be detected will never have exactly the same properties so that the reaction of the safety system might be different.

Anyway, two active safety systems aiming at one and the same situation (or being called the same) and whose data are therefore collected in the same category might have different functionalities. This would lead to the situation the effects calculated are false or allocated to the wrong device. This situation occurs likely if different manufacturers produce similar active safety devices but implement their own control strategy or philosophy. E.g. VSC systems of different manufacturers or even in different vehicle models of the same manufacturer are not identical. In accident studies therefore the group of relevant accidents which the safety system is pertinent in has to be selected carefully.

As it is often the case when doing statistics effects do not depend on one single variable but on a bundle of covariates. For accident studies these are e.g. driver age and gender, road conditions, weather and visibility conditions, mass and power of the vehicle etc.

The results of an analysis with regard to a safety system also might be biased by some side effects: new vehicles with a special safety system might e.g. have a different (perhaps more careful) driver population or the effect of the safety system is compromised by misuse (driving in darkness with the night vision picture only). Also active safety systems are mostly not introduced alone but the new car model is fitted with a combination of safety measures which in some cases even can only be bought as a bundle. Thus it will be difficult to allocate positive impacts to the appropriate safety system. Such side effects have either to be accepted or to be eliminated by selecting the right accident subsets as in [9].

Table 2 summarises the limitations and restrictions for collecting and evaluating active safety data in in-depth accident studies.

Real accident causations unknown
Accident reconstruction is missing
Small numbers of relevant accidents occur
Long time span needed to fill the database
Few vehicles equipped with interesting safety systems
Active safety systems act depending on manufacturers' philosophies
Result biased
Covariates and their influence unknown
Results often not significant

Table 2: Limitations for collecting and evaluating actice safety data

Conclusion

Since active safety systems are expected to have a significant and increasing influence on reducing accidents, fatalities and injuries in the future this should show up in accident databases as well. In-depth studies therefore began to include active safety issues as new variables and to collect corresponding data. An assessment of the impact of active safety measures by means of accident analyses should help to optimise the systems and give advice for policy making with regard to vehicle safety.

For such an impact assessment it is necessary that accident data can offer information about the following items:

- Was the vehicle equipped with the safety system of interest?
- If yes, was the system enabled?
- If yes, did the system influence the course of the accident?
- Could a system which was not fitted to the vehicle have had an accident avoiding or mitigating effect if it was fitted?

To be able to answer these questions and as a consequence to determine the safety benefits of a system the user of the accident database needs as much cases and as detailed figures as possible. A sufficient number of cases will be reached earlier if more vehicles are equipped with the relevant systems. For the majority of active safety devices this will require to wait for several years.

Another prerequisite is that the real accident causes are known. Only with this knowledge it can be assessed if the active safety system has had a chance to interfere and do its beneficial job. Especially the case examining the effect of a brake assisting system mentioned above shows that accident reconstruction as a part of in-depth study is indispensable especially for active safety issues.

Although the number of recordings for active safety is still small and biasing effects do not allow for carrying out statistical evaluations the examination of single cases already helps to get insight into the accident avoiding mechanisms and the possible benefits of active safety devices. Especially for vehicle or system manufactures information gathered from these single cases can therefore be useful already at the time being.

As the examples for ESP show in-depth accident studies can already be used to evaluate the safety benefits for a few systems. For other systems some time of data collection will be needed. But if the demonstration of safety benefits will be possible for a safety system only fitted to a minority of vehicles now this would indicate a big potential for traffic safety since a coming high market penetration would lead to a high safety gain in the future. Under the assumption that the equipment rates grow linearly the effects in accidents and accident databases should increase nearly to the square since the vehicles being equipped once will remain in the stock for years.

There is no doubt that starting to collect active safety data was a necessary and sensible step but patience is needed for searching for effects in in-depth accident databases.

References

[1] C. TINGVALL, M. KRAFT, A. KULLGREN, A. LIE: The effectiveness of ESP (electronic stability program) in reducing real-life accidents, Traffic Injury Prevention, 5, 2004, S. 37-41

[2] C.M. FARMER: Effect of electronic stability control on automobile crash risk, Traffic Injury Prevention, 5, 2004, S. 317-325

[3] "Electronic stability control reduces deaths, especially in single-vehicle crashes", Insurance Institute for Highway Safety Status Report, Vol. 40, No. 1, January 3, 2005

[4] R. SFERCO, Y. PAGE, J.-Y. le COZ, P. FAY: Potential effectiveness of Electronic stability programme (ESP) – what European field studies tell us, ESV paper No. 2001-S2-O-327, Amsterdam 2001

[5] J.-P. KREISS, L. SCHÜLER, K. LANGWIEDER: The effectiveness of primary safety features in passenger cars in Germany, ESV, 2005

[6] M. AGA, A. OKADA: Analysis of vehicle stability control (VSC)'s effectiveness from accident data, Proceedings of the 18th International Technical Conference on the Enhanced Safety of Vehicles, Nagoya, Japan, May 2003, ESV paper 541, NHTSA, DOT HS 809 543

[7] U. GRÖMPING, U. WEIMANN, S. MENTZLER: Split-register study: A new method for estimating the impact of rare exposure on population accident risk based on accident register data, in: 1st International Conference on ESAR “Expert Symposium on Accident Research”, Berichte der Bundesanstalt für Straßenwesen, Heft F55, Bergisch Gladbach, April 2005, S. 95-101

[8] L. HANNAWALD: Computerized case by case analysis for evaluation of primary safety systems regarding accident prevention, in: 1st International Conference on ESAR “Expert Symposium on Accident Research”, Berichte der Bundesanstalt für Straßenwesen, Heft F55, Bergisch Gladbach, April 2005, S. 210-215

[9] Y. PAGE, S. CUNY: Is ESP effective on French roads?, in: 1st International Conference on ESAR “Expert Symposium on Accident Research”, Berichte der Bundesanstalt für Straßenwesen, Heft F55, Bergisch Gladbach, April 2005, S. 256-267

[10] GIDAS Codebook 2005

[11] S. BUSCH, H. BRUNNER, R. ZOBEL: Prognose des Sicherheitsgewinns unfallvermeidender Systeme, ATZ 04/2006, S. 304-307

M. Jänsch, D. Otte, C. Krettek
Accident Research Unit and Trauma Department, Hannover Medical School

Fatal Traffic Accidents in Lower Saxony– A New Approach to Accident Sampling and Analysis of Accident Causes and Configurations

Abstract

In the context of this study, different data sources for accident research were examined regarding their possible data access and evaluated concerning the individual quality and extent of the data. Analyses of accidents require detailed and comprehensive information in particular concerning vehicle damages, injury patterns and descriptions of the accident sequence. The police documentation supplies the basic accident statistics and is amended in the context of the forensic treatment by further information, e.g. by medical and technical appraisals and witness questionings.

As a new approach to the data acquisition for the analysis of fatal traffic accidents, the information was made usable which was collected by the police and by the investigations of the public prosecutor. The best strategy for obtaining reliable, extensive and complete data consists of combining the information from these two sources: the very complete, but elementary statistic data of the Niedersächsisches Landesamt für Statistik (Lower Saxony State Authority of Statistics), based on the police documentation as well as the very extensive accident information resulting from the investigation documentation of the public prosecutor after conclusion of the procedure, the so-called Court Records.

Of all 715 fatal traffic accidents, which happened in the year 2003 in the German State of Lower Saxony, 238 cases were selected by means of a statistically coincidental selective procedure based on a statistically representative manner (every third accident). These cases cover the investigation documents of the 11 responsible public prosecutor's offices, which were requested and evaluated while preserving the data security. Of the 238 cases 202 cases were available, which were individually coded and stored in a data base using 160 variables. Thus a data base of a sample of representative data for fatal accidents in Lower Saxony was set up. The data base contains extensive information concerning general accident data (35 variables), concerning road and road surface data (30 variables), concerning vehicle-specific data (68 variables) as well as concerning personal and injury data (27 variables).

Introduction and Purpose

Traffic accident data of a country or a state, which are relevant for the research of accidents, can be collected from a number of different sources. The standard way of accident data acquisition is to use primary police documents in form of the police report. The research report of the BASt from the year 1976 [1] indicates that there are about 50 items of information available, which have changed over the years, and the number of data collected has rather decreased. Further possibilities exist in the data collection at the site of the accident by scientific teams and by the evaluation of insurance documents, for example of the GDV. Alternatively a new approach for the procurement of accident-relevant data was selected: For the year 2003 traffic accidents in Lower Saxony with fatal outcome were examined on the basis of information from the investigation documents of the public prosecutor's offices and collected in a data base. The Niedersächsisches Landesamt für Statistik (Lower Saxony State Authority of Statistics) (NLS) supplies very complete data records containing all the basic data to the extent of the police accident report. In contrast, the documents of the public prosecutor's offices frequently contain quite profound and detailed data. For getting hold of the investigation documents of the public prosecutor, it was necessary to figure out the register number of the public prosecutor's office by using the police documentation.

The Data of the Niedersächsisches Landesamt für Statistik (Lower Saxony State Authority of Statistics)

The first source of accident data concerning traffic accidents with fatal consequences in Lower Saxony is the data set of the Niedersächsisches Landesamt für Statistik, NLS. The NLS collects data concerning every traffic accident in Lower Saxony which is recorded by the police and where as a consequence of the accident there is at least one tow away vehicle or which resulted in the injury of one or more persons. A defined data record is conveyed to the Federal Statistical Office from the data bases of the states of the Federal Republic, in order to achieve an overview of the total situation in Germany.

The basis of the NLS data base are police statistics based on police reports (level 1). Therefore the data records of the NLS are very similar to those of the police data bases existing at police headquarters. Additionally, here however further data are supplemented (in particular vehicle-specific data) from other national data bases (e.g. the Kraftfahrt-Bundesamt [Federal Motor Transport Authority]) (level 2).

The NLS recorded data concerning 715 traffic accidents with fatalities in Lower Saxony in the year 2003. For each person involved in an accident the NLS data record consists of 108 different variables. This results in the fact that an accident can have several data records according to the number of involved persons. The structure of the NLS data records can be divided into 4 different categories:

1. Accident-specific data. In this category data relating to 57 variables in view of the accident scene, date and time as well as the kind of the accident are collected.

2. Data referring to the road user. Here the focus is on the data of the road user (e.g. the driver of a vehicle, a pedestrian or vehicle-specific data). The 34 variables of this category refer both to personal data and the age, the nationality of a road user or the cause of accident as well as to technical data of the vehicle like e.g. motor vehicle type, load, engine data etc.

3. Injured passengers. In this category, 10 variables, concerning the age, sex and the injury severity of up to 10 passengers per vehicle are indicated.

4. Data processing characteristics. The data in this category are used internally for data processing purposes. These 7 variables are not relevant here.

The Investigation Documents of the Public Prosecutor's Offices as a Data Source

With each traffic accident with fatal consequences the appropriate public prosecutor's office is informed by the investigating police department. The area of Lower Saxony is divided into 11 responsible public prosecutor's offices. Therefore the appropriate public prosecutor's office investigates the accident dependent on the location. Figure 1 shows the competency areas of the 11 public prosecutor's offices in Lower Saxony.

In the context of the public prosecutor's investigation by the corresponding public prosecutor's office an investigation document concerning the traffic accident is established on the basis of the police report. For this reason an investigation document exists at the corresponding public prosecutor's office for every one of the 715 fatal traffic accidents in Lower Saxony in the year 2003. These investigation documents are usually very extensive data sources, which also offer very extensive data for the research of accidents. Since the public prosecutor's offices examine the traffic accidents based on a legal background, the investigation documents can contain a variety of different documents and sources of information (level 3), which may, however, be equally missing in other investigation documents. Among the most frequent documents and sources of information which were gathered in the investigation

Figure 1: Competency areas of the 11 public prosecutor's offices in Lower Saxony

documents concerning a fatal traffic accident belong:

- traffic accident notification of the police,
- traffic accident investigation report of the police,
- photo report of the police,
- death certificate,
- testimonies,
- damage or accident reconstruction appraisals,
- autopsy report or medical injury opinion.

Usable information from the investigation documents of the public prosecutor's office

The data, which can be found in the investigation documents can be subdivided into the following four categories: data of the surrounding area, vehicle data, data concerning the persons and injury data.

The data of the surrounding area contain information concerning the site of the accident, the climatic conditions, the cause of accident etc. This is normally also supplemented by photos of the accident site. In some cases, an expertise of an accident reconstruction is present, which supplies further specific information.

The vehicle-specific data to be found in the investigation documents are fundamental information about the vehicles, the technical condition of the vehicles and the damage to the vehicles. This usually includes also photos of the vehicles. In some cases also an expertise of the damage is present.

The personal data from the investigation documents supply specific data like age, sex, occupation, driving license etc. Rather fundamental information concerning injuries is found in the police reports or death certificates. This information is present in nearly all investigation documents. As very extensive source of injury information some documents additionally contain autopsy reports, injury appraisals and/or photos of injuries as well as of vehicle deformations.

Data Acquisition Methodology

In order to obtain as representative accident data as possible for Lower Saxony regarding the traffic accidents with fatal consequences, there is also the possibility of taking a statistically representative sample aside from the use of all individual documents. Examining all fatal traffic accidents with over 700 investigation documents of the public prosecutor's offices (total data collection) would have entailed an excessive personnel expenditure. For this reason, a representative selection was taken from investigation documents of the Public Prosecutor. In order to ensure that all judicial procedures for the investigation documents were already concluded and therefore the availability of the documents was given, the year 2003 was selected for the collection year.

The number of approx. 200 investigation documents constitutes a sufficient number of investigation documents for statistically representative purposes, which could be examined at a justifiable personnel expenditure.

In order to be able to make representative statements from the data of the public prosecutor's investigation documents for Lower Saxony, a sampling method was used for the selection of the documents, where the sub-sample was formed from all accidents with fatal consequences. Initially for this purpose the basic data concerning all traffic accidents with fatal consequences in the year 2003 were transmitted by the NLS. These data contain:

District, county, municipality, accident day, accident month, accident year, weekday, accident time – hour, accident time – minute, number of participants, number of fatalities, number of severely injured persons, number of slightly injured persons, type of accident, characteristics of the accident scene, special features of the accident scene, set of lights, speed limit, lighting conditions, road conditions, impact on obstacles at the roadside, effect of alcohol, car not road-worthy, general provisional causes, local position, accident category, type of accident, road class, road number, km specification, driving direction, road code, causes of accident – 1. Cause, causes of accident – 2. Cause, causes of accident – 3. Cause, leaving the scene of the accident, date of birth, age in years, resident aliens in Germany, nationality plate, license plate administrative district, number of vehicle occupants, accident consequences of involved persons, 1st passenger: inj./sex, 1st passenger: age in years, 2nd passenger: inj./sex, 2nd passenger: age in years ... 10th passenger: inj./sex, 10th passenger: age in years, blood alcohol concentration, required driving license exists, date of issue of license: month, date of issue of license: year, type code: vehicle manufacturer, type code: basic type, type code: type execution, type code: check digit, vehicle type, body style, engine performance in kW, capacity in ccm, max. speed, number of axles, propelled axles, curb weight in kg, permissible total weight, registration date, label for additional expert's opinion, hazardous materials hazard category, hazardous materials digit/letter, no. of the exemption regulation, release of hazardous materials, amount of damages to property, registration date in years.

By means of a statistic random principle, every third accident was selected and the appropriate court record was procured from the 11 different public prosecutor's offices. From the complete list of the NLS with 715 deadly traffic accidents from the year 2003, n=238 of cases were selected and were to be examined.

At the different interfaces of the file access (police, public prosecutor's office) the data record structure was described in order to be able to later discuss the possibilities of the use regarding type, scope and quality of the information.

In order to be able to refer to the 238 selected investigation documents of the 11 responsible public prosecutor's offices, first some foundations had to be laid. Since the investigation documents naturally contain personal information and thus are subject to the protection of privacy, all members of the investigation team who handled the investigation documents were obliged to sign a confidentiality agreement. This is a confidentiality agreement according to the Verpflichtungsgesetz (Law on the Commitment of Persons to Secrecy) dated March 2nd, 1974 (BGBl. I S. 469).

In the second step it was necessary to request the public prosecutor investigation documents from responsible public prosecutor's offices using the appropriate reference number. 202 investigation documents could be made accessible by the public prosecutor's offices. All 202 requested investigation documents arrived within a relatively small period of time and had to be returned to the appropriate public prosecutor's offices after a relatively short retention period. For this reason it was necessary to first digitize the investigation documents using scanners and then to store the copies temporarily. These digital copies were then used for coding and entering of the accident-specific data after they were made anonymous regarding personal data.

Data Structure

The data both from the public prosecutor's investigation documents and from the tables of the NLS were combined in a data base. This is a data base that was adapted particularly to the information content of the investigation documents and the data of the NLS. For each case the data in 160 different variables and text fields were coded and stored in the data base. Since the 202 recorded fatal accidents constitute a representative selection of all 715 fatal accidents in Lower Saxony in the year 2003, a representative data base extending beyond the statistic level was created for accidents with fatal consequences in Lower Saxony. The created data base is called FALS (Fatal Accidents Lower Saxony). The structure of this data base with 160 variables per case can be outlined as follows in Figure 2. A list of the variables can be found in table 1 in the Annex.

For the 202 fatal traffic accidents from the year 2003 in Lower Saxony recorded in the data base, the data of 337 traffic participants involved in an

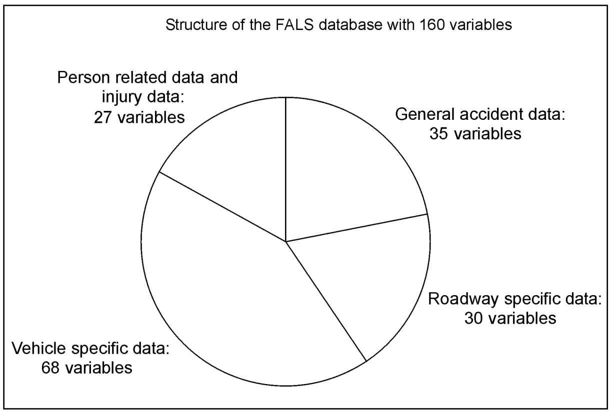


Figure 2: Structure of the data base FALS containing fatal accidents in Lower Saxony

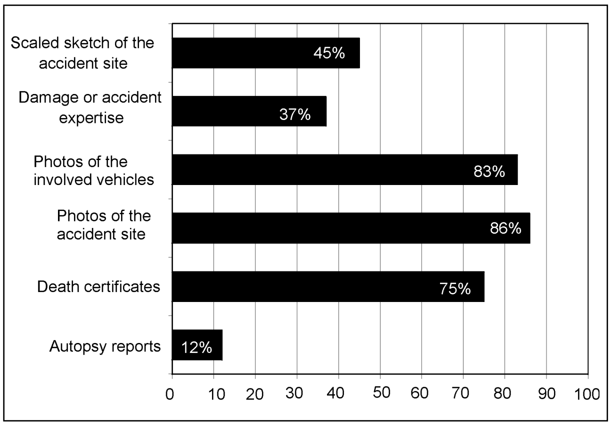


Figure 3: Percentage of the occurrence of information sources in public prosecutor's investigation documents

accident and of 482 participating persons were coded. Of these persons 225 persons (47%) were fatally injured, 67 persons (14%) were severely injured, 75 persons (16%) were slightly injured and 115 persons (47%) remained unhurt.

The public prosecutor's investigation documents can contain a multiplicity of different sources of information. Figure 3 shows an overview of the availability of these sources of information in the investigation documents.

Photos of the accident site and of the vehicles were present in over 83% of the cases. Scaled sketches of the accident place however existed only in 45% of the cases and technical expert's opinions in only 37%. Autopsy reports only existed in 12% of the cases. This surely constitutes a special situation in Lower Saxony. It was reported that for the State of Bavaria for instance in about 80% of the cases an autopsy is performed [2]. In only two cases (1%) there was also a forensic expert's report to answer the question of the use of a belt.

Classification of accident constellations

In the course of the coding of the selected sample of 202 accidents, the accident type classification of the ISK (Institut für Straßenverkehr Köln – Institute for Traffic Cologne) was applied. This provides an accident type classification in 7 main categories and subsequently into several sub-categories of the respective main categories. However when setting up the accident report, the police uses the classification into the 7 main categories only and not the more extensive classification into the various sub-categories by means of a 3-digit code. In the context of this study regarding the 202 court records the extensive, more detailed classification of the accident type code having 3 digits was used. From the sample of the 202 accidents it turned out that with 96 accidents 48% of all accidents were driving accidents. The second most frequent type of accident was the accident in longitudinal traffic at 15% (30 accidents), followed by turning/intersecting accidents at 12% (25 accidents), turning accidents at 10% (21 accidents) and crossing accidents at 9% (18 accidents). The accident types occurring least frequently were accidents by stationary traffic with only 2% (5 accidents) and other accidents, which could not be classified into the categories already mentioned, at 3%. Figure 4 shows the distribution of the accidents of the sample of 202 accidents classified according to accident types compared with the situation in all 715 deadly accidents in Lower Saxony in the year 2003. It shows that the sample exhibits a good representativeness regarding the classification into the 7 accident types. Slight deviations result from the fact that the

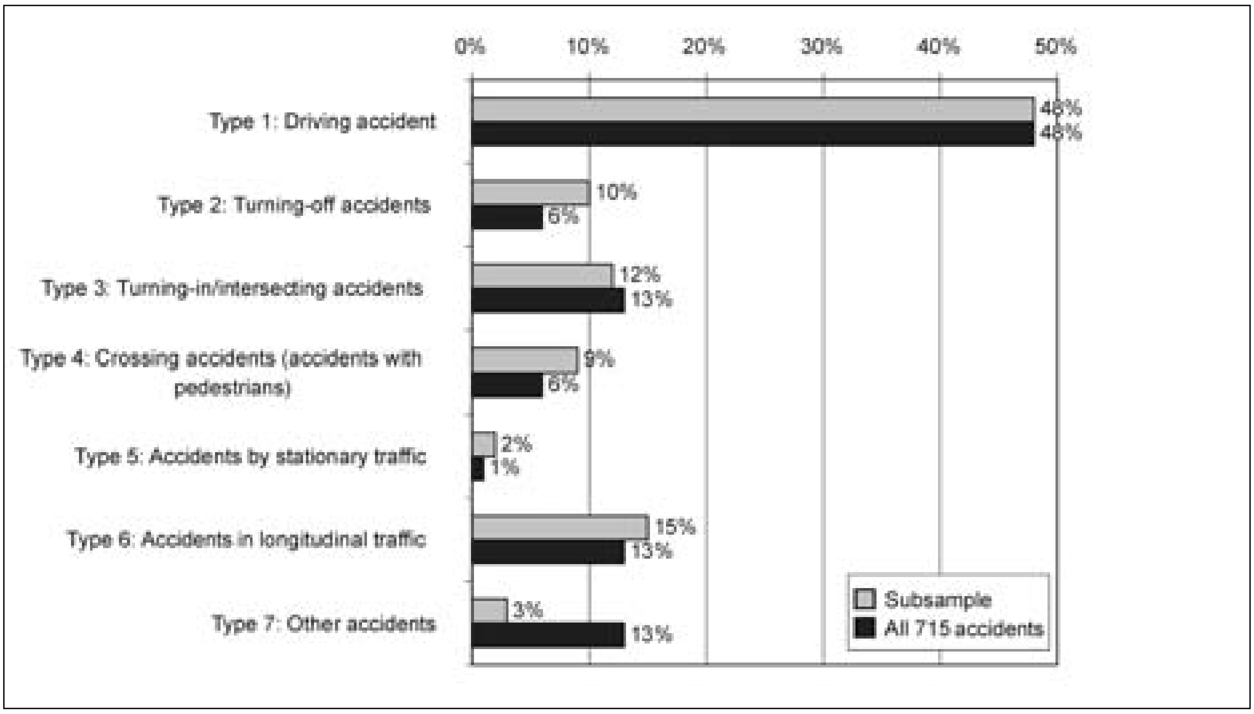


Figure 4: Distribution of the accidents into the 7 accident types. Indicated for all 715 fatal accidents in Lower Saxony in 2003 und for the random sample of 202 accidents

classification of the 715 accidents of the NLS was made by the police at an early stage, when possibly not all circumstances of the accident had been known. The classification of the 202 accidents from the sample, however, was based on the complete information content of the public prosecutor's investigation documents after the conclusion of the forensic procedure.

A detailed evaluation of these accident types in the sub-categories resulted in the following accident structure for the sample:

Driving accidents
Within the 96 driving accidents 60 accidents occurred in a curve. Left and right curves have a similarly high percentage. Of the remaining 36 driving accidents, 34 accidents occurred on straight roads and only 2 accidents in other situations.

Turning accidents
The largest share of the 21 turning accidents were accidents between a vehicle turning left and an on-coming vehicle (14 accidents). Five accidents were accidents between a vehicle turning left and a following vehicle.

Turning/intersecting accidents
Within this category the accidents were distributed predominantly on two sub-categories. 13 of the accidents happened due to conflicts between a vehicle required to wait and one coming from the left with the right of way. Of the remaining 12 accidents in this category 8 accidents happened due to conflicts between a vehicle required to wait and one coming from the right with the right of way and 4 accidents can be distributed to other sub-categories.

Accidents with pedestrians
Of the 18 accidents with pedestrians, 8 accidents occurred due to a conflict between a vehicle and a pedestrian crossing from the right side. Only 4 accidents occurred due to a conflict between a pedestrian coming from the left side and a vehicle. The remaining accidents with pedestrians can be distributed to other sub-categories.

Accidents in stationary traffic
3 of the 5 accidents in stationary traffic happened due to a conflict between a vehicle and a vehicle parking and/or being stationary in front.

Accidents in longitudinal traffic
The majority (13 accidents) of the 30 fatal accidents in longitudinal traffic fall into the sub-category "conflict between encountering vehicles". Another 5 accidents happened due to a conflict between a vehicle and a vehicle preceding it on the same lane. The remaining 12 accidents in this category can be distributed to approximately the same measure on the remaining sub-categories.

Other accidents
Of the 7 accidents not fitting into any of the preceding categories 5 accidents fall into the sub-category "accident by sudden physical inability of the road user".

Figure 5 shows the 10 most frequent types of fatal accidents in accordance with the detailed ISK classification with sub-categories.

It is obvious that the type of accident "driving accident in a curve" is the most frequent type of fatal accident at nearly 30%. The secondary most frequent type of accident is at nearly 17% the driving accident on a straight stretch of the road. The remaining 8 types of accidents lie relatively closely together at frequencies from 2.5% to 7%. Here, no clear order of the frequency of the occurrence can be given, as for only 202 accidents the statistic inaccuracy would be too great.

In order to take the specific characteristics and collision situations of the different road users into consideration, the most frequent type of accident for passenger car drivers, truck drivers, pedestrians, riders of motorbikes and for cyclists was determined (Figure 6). Of the sample containing 202 accidents 167 accidents involved a passenger car, with the most frequently occurring type of accident being a "driving accident in a curve" at 31%. Of the 39 accidents with truck participation the type "accident in longitudinal traffic with oncoming traffic" occurred most frequently at 15%. Of the 32 accidents with motorcycle participation within the sample, the type of accident "turning accident with oncoming traffic" was most frequently represented at 25%. Of the 20 accidents with bicycle involvement, the type "turning/intersecting accident with priority traffic from the left" occurred most frequently at 20%. In fatal accidents, in which pedestrians were involved (21 accidents), in 33% of all cases the most frequent type of accident turned out to be the "crossing accident with pedestrian from the right".

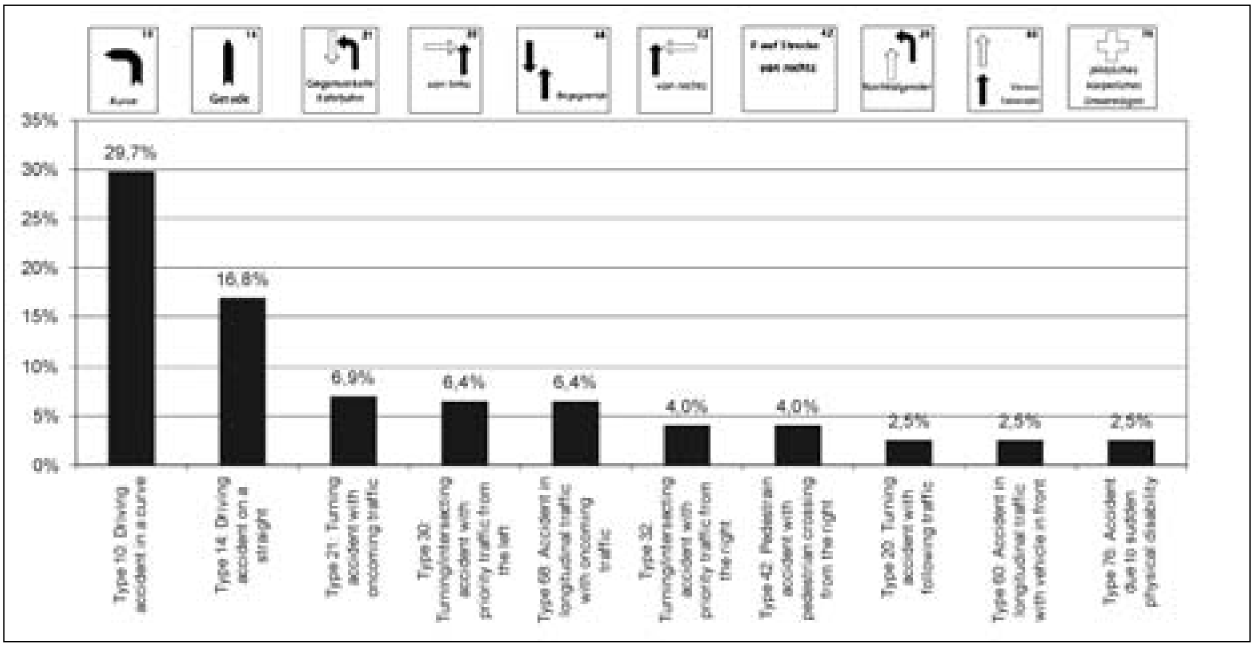


Figure 5: Representation of the 10 most frequent accident types according to the detailed classification

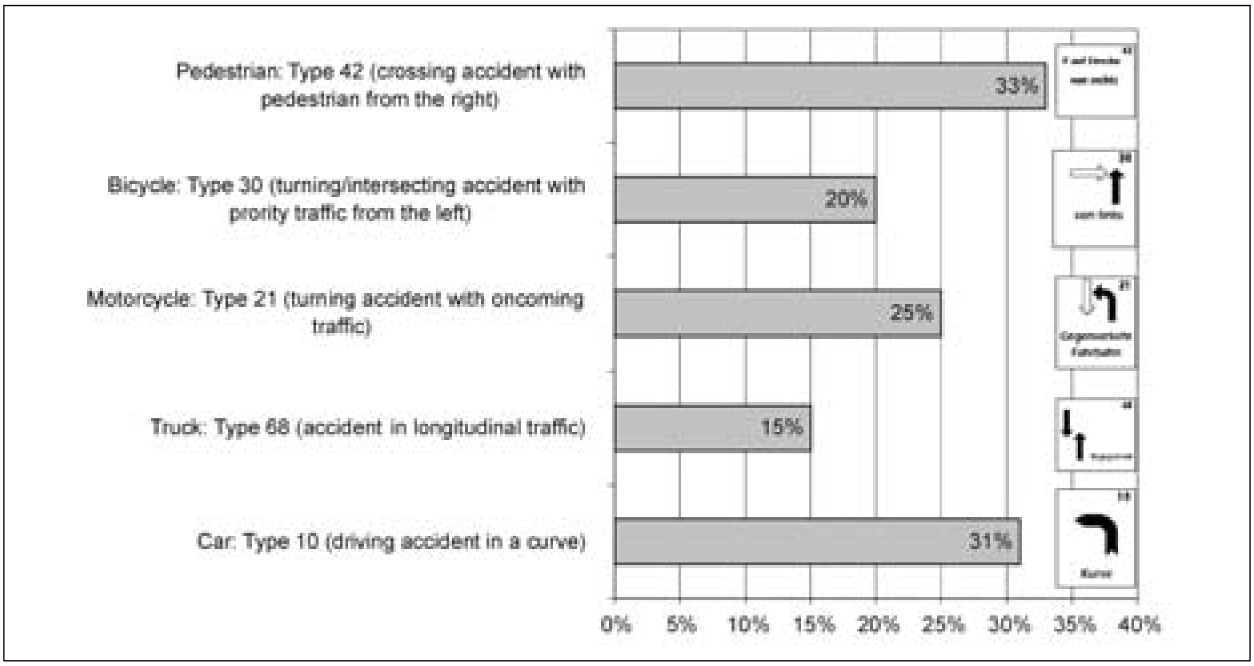


Figure 6: Proportion of the most frequent type of accident as a function of the motor vehicle type involved in a fatal accident

Evaluation of Representativity – Accident Structure and Injury Situation

The question regarding the representativity of the methodically collected information here by means of procedures of random sampling arises, so that in the following a selection of statistic evaluations was conducted, in order to also create a comparison of this sample to the known results of all accidents besides the comparison of accident and injury situations of killed road users in Lower Saxony. For this purpose most figures show the values from the table of the NLS (for all 715 fatal accidents in Lower Saxony 2003) as well as the values from the data base FALS with the data from the public prosecutor's files of inquiry (selection of 202 fatal accidents in Lower Saxony 2003). While the data from the NLS were frequently coded on site by the police, after the study of the files of inquiry the data were coded again, independently of the police coding. On the one hand the police may not have had access to all information (e.g. appraisals) at the time of coding and on the other hand some variables leave more room for different interpretations (e.g. lighting or road conditions). The larger deviations in some areas are possibly due to this fact.

1. Structure of fatal accidents in Lower Saxony

A reasonable accordance between the selected sample and all road users killed in Lower Saxony appears in the distribution of the characteristics: type of accident, kind of road and type of local area. With the detailedness of the available information of the sample cases even accident parameters such as collision speed could be determined.

As Figure 7 shows, according to the sample most fatal accidents in Lower Saxony occurred on federal highways and state highways at 30% and 29% in the year 2003. Significantly fewer fatal accidents occurred on the motorways in Lower Saxony at 8% and on the usually calm rural roads (10%). The percentages of the total group of fatalities showed almost identical values (±1%). This confirms the good representativity of the database of FALS and thus of the selective procedure.

Also Figure 8 giving the distribution of the fatal accidents depending on the local area shows the same data in the sample as in the total data collection, 79% of the accident victims occurred outside urban areas (total data collection 80%).

Due to the high proportion of passenger cars in traffic, in the sample 63% of the vehicles involved were passenger cars (65% in the total data collection) – Figure 9. Trucks were involved at only 15% (total data collection 14%) and motorcycles only at 9% (also 9% in the total data collection). Of the non-motorized road users, cyclists were involved in 6% and pedestrians in 7% (total data collection in each case 6%) of the cases.

Figure 10 shows the most frequently occurring kinds of fatal accidents. Leaving the carriageway (to the left or to the right) occurs in 43% of all accidents. The second most frequent kind of accident among the fatal accidents is a collision with an oncoming vehicle or with a crossing vehicle.

37% of the public prosecutor's files of inquiry from the sample (202 cases=100%) contain a technical expertise. In the context of these appraisals for 84 people involved in 53 traffic accidents a collision speed was determined by experts. Figures 11 and 12 show the distribution of the determined velocity

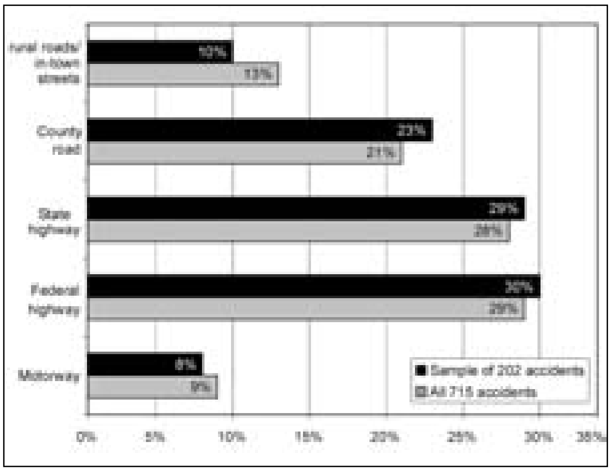


Figure 7: Distribution of the fatal accidents according to the type of road for the situation in Lower Saxony in 2003 (715 accidents) and for the selected 202 accidents

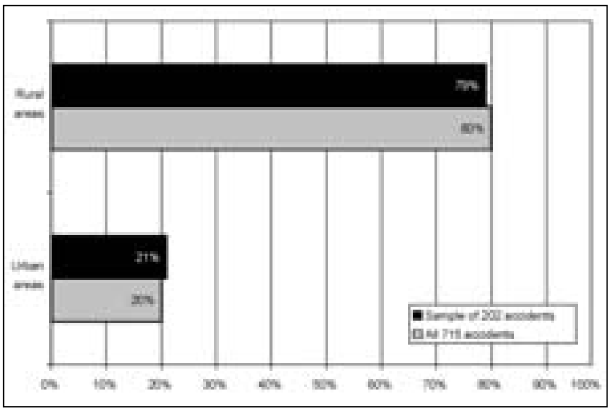


Figure 8: Distribution of the fatal accidents according to the local area in Lower Saxony in the year 2003 (715 accidents) and for the sample of the 202 accidents from the data base

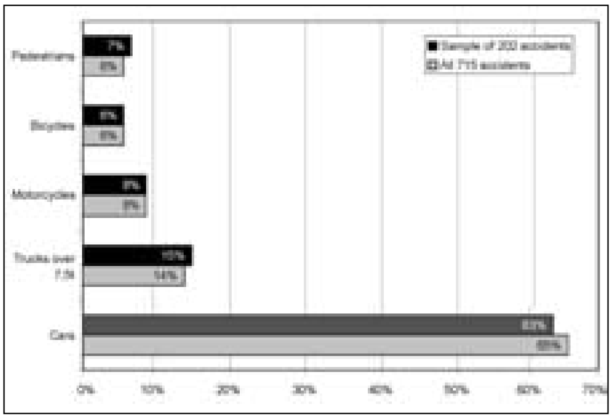


Figure 9: Distribution of the kind of the road users, who were involved in fatal accidents

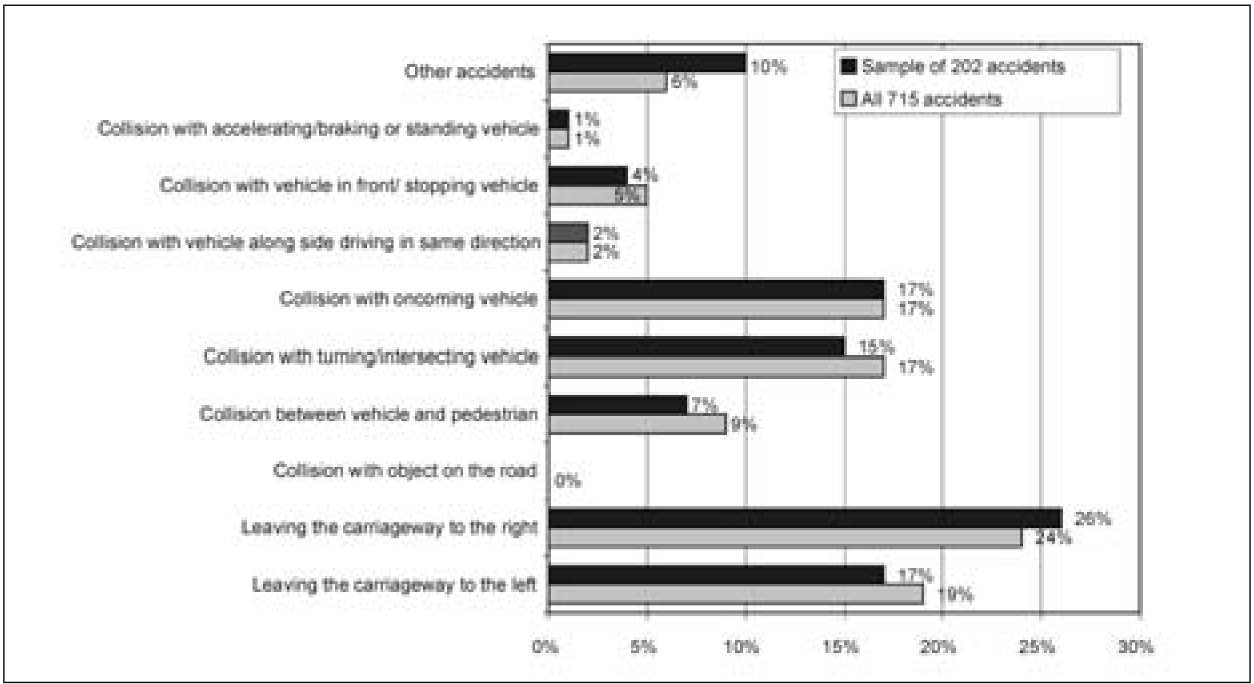


Figure 10: Distribution of the type of accident in all fatal accidents as well as in the accidents of the database from the public prosecutor's files of inquiry

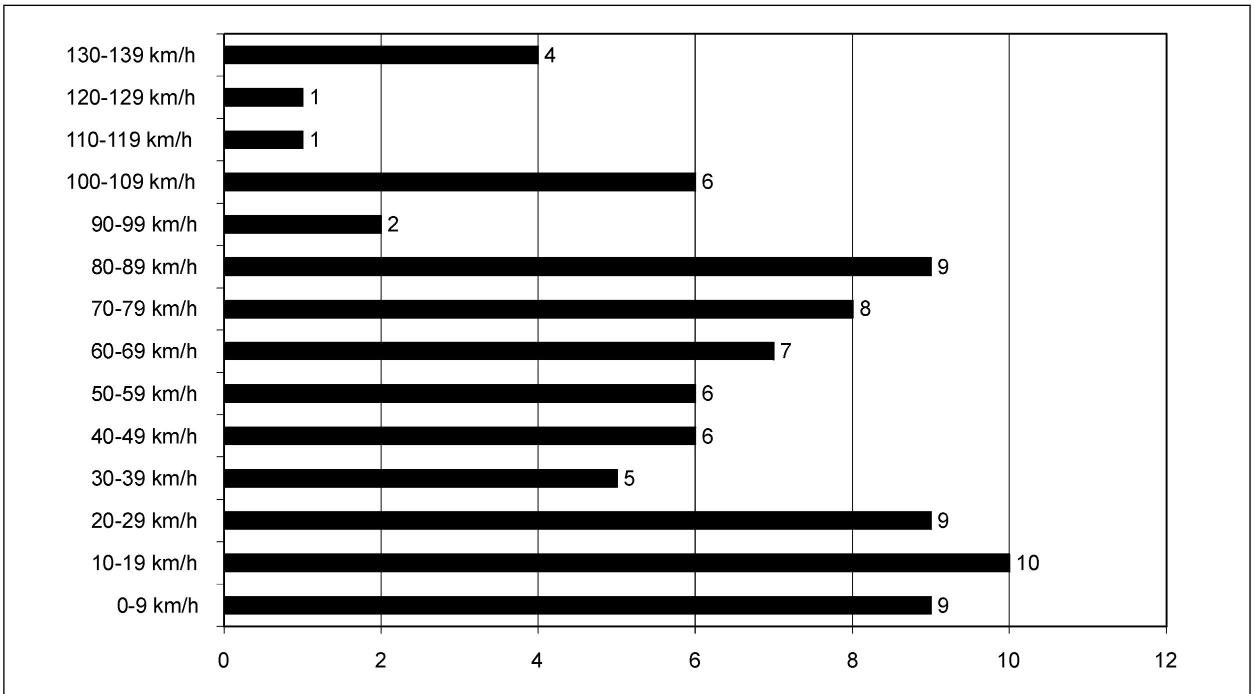


Figure 11: Distribution of the number of people involved in an accident on the collision speeds in fatal accidents with expert's opinions

values for the 84 people involved in accidents. It is obvious that the range up to a collision speed of 30km/h is most frequently represented. Within this range the accidents with pedestrian and cyclist occurred. Beyond 30km/h, the number of people involved in accidents increases with the corresponding collision speed up to a range of 90km/h, as higher collision speeds generally result in a greater injury severity. People involved in an accident with collision speeds of more than 80km/h are still relatively frequently found at approximately 25%. It is to be kept in mind that generally a speed-reducing condition preceded the collision, such as braking or swerving. The driving speeds at accident

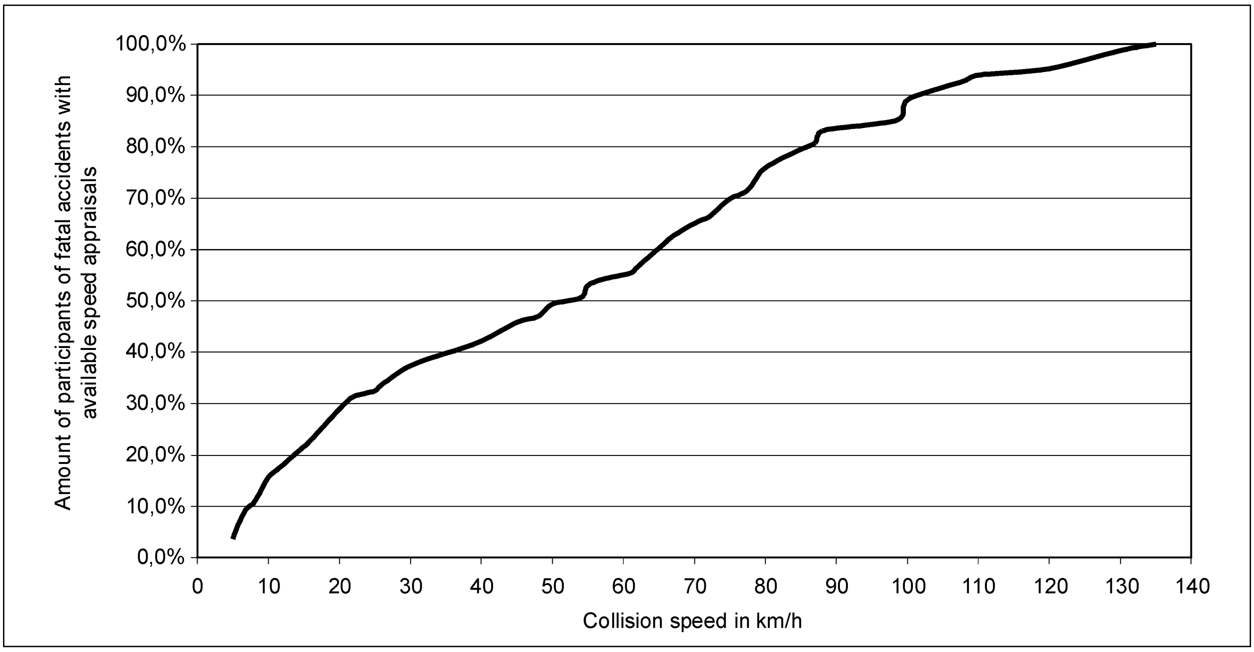


Figure 12: Number of persons involved in fatal accidents with speed appraisals as a function of the collision speed applied as cumulative incidence

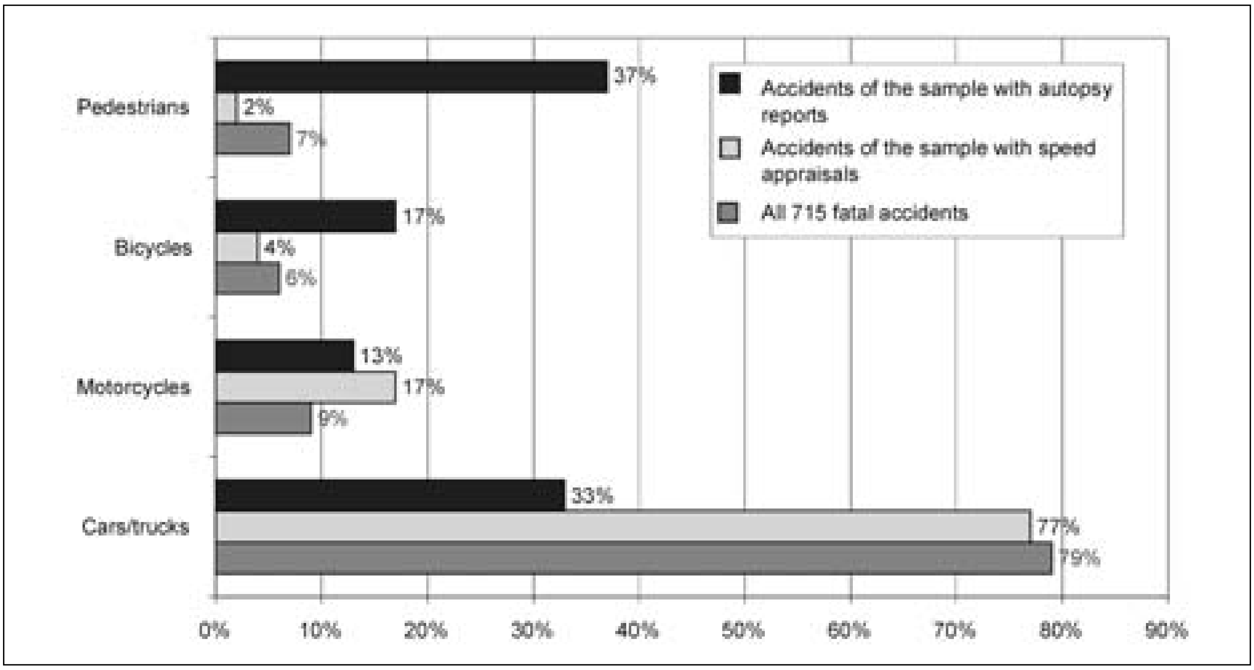


Figure 13: Distribution of the type of road user with all 715 fatal accidents in Lower Saxony in 2003 as well as in all accidents of the sample in which a speed appraisal is present and in all accidents of the sample in which an autopsy was performed

initiation usually exceed the corresponding collision speeds (Figure 11 and 12).

For the statistically representative significance of the represented distribution of the collision speeds (Figure 11 and 12) it is of importance that the speed appraisals which were ordered by the police and/or by the public prosecutor's office show a certain representativity regarding the total situation.

Figure 13 shows the distribution of the road users for all 715 fatal accidents in Lower Saxony compared to the sub-sample for all accidents with speed appraisals from the sample of 202 fatal accidents as well as for all accidents with autopsy reports from the sample. The proportional frequency of the participation of the 4 road user types pedestrians, cyclists, motorcycles and passenger car/truck is represented in each case.

Here the representativity of the cases where a technical appraisal with collision speeds is present is given, at least regarding cars/trucks and cyclists. The portion of the motorcycles with the speed appraisals at 17% is nearly twice as high as the total number of accidents that occurred (9%). Fatal accidents with pedestrians however are underrepresented at 2% of the cases as opposed to 7% of the total number of accidents that occurred. This is surprising, since it has been assumed that in fatal pedestrian accidents there would be a particular interest at the side of the public prosecutor to determine the speed by means of a technical appraisal. It seems to be greater however, if passengers in cars suffer from fatal consequences of accidents.

A relatively clear correlation of autopsy orders for certain groups of road users can be seen. At 37% of the autopsies the pedestrians are strongly over-represented, as their corresponding proportion in the 715 fatal accidents in Lower Saxony is 7%. The same applies to bicycle riders. While 17% of all traffic fatalities from the sample on whom an autopsy was performed were cyclists, these were involved only to 6% in fatal accidents. Autopsies were performed on 13% of the motor cyclists, whereas only 9% were involved in fatal accidents. A different picture is revealed when the road user is a passenger car/truck. Persons in this type of motor vehicle are involved in 79% of the fatal accidents in Lower Saxony. They were subject to autopsies only at 32% of the traffic fatalities that occur, however. Thus clearly a statistically representative analysis from autopsy data is not possible, autopsy protocols are often oriented at forensic criteria and provide a detailed description of the injuries. Of the selected sample of 202 fatal accidents in Lower Saxony in the year 2003, autopsies were performed on only 24 cases (12%).

2. Injury severity and injury pattern of fatal accidents in Lower Saxony

The injuries of the autopsy reports were coded in accordance with the “Abbreviated Injury Scale” AIS 2005, so that a statistic evaluation was possible. The distribution of the injury severity of all 278 coded injuries in accordance with the AIS classification is represented in Figure 14. AIS 1 corresponds to a slight injury, AIS 2 to a moderate injury, AIS 3 to a severe injury, AIS 4 to a serious injury, AIS 5 to a critical injury and AIS 6 to an injury not treatable at the time. The AIS value of 9

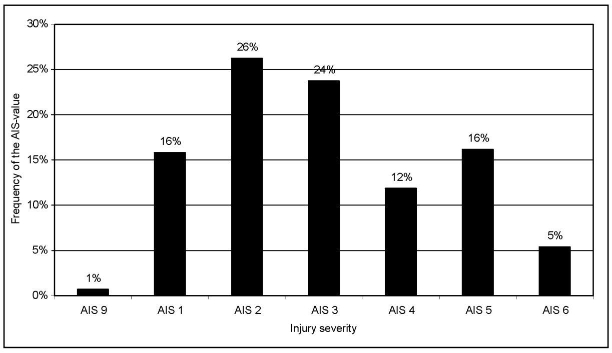


Figure 14: Distribution of injury severities in accordance with AIS covering all 278 injuries of the 24 traffic fatalities on whom autopsies were performed

designates unknown injuries, which are represented at less than one per cent here.

It is shown that moderately severe injuries AIS 2 and AIS 3 occurred most frequently at around 25% each with the accident victims. However only 16% of the injuries were slight injuries (AIS 1). Of the severe injuries, which often led to fatality, 12% were AIS 4 as well as critical injuries (AIS 5) at 16% and AIS 6 (5%), altogether thus 21%, were particularly frequently represented.

In Figure 15, the distribution of the 159 heaviest injuries (all injuries starting from AIS 3) is represented according to the body regions. Additionally these injuries are sub-divided according to the injury severity into the categories AIS 3, AIS 4, AIS 5 and AIS 6. It is shown that head injuries are strongly represented within the 4 groups of the most severe injuries. There were virtually no injuries to the face or to the neck of AIS values of AIS 3 and more. Thorax and stomach injuries however occurred more frequently in all groups of AIS 3 and more, just like head injuries. Severe injuries to the spinal column are rare. This finding contradicts the statement of Figure 16, where at 7% of the cases, spinal column injuries were the most severe injuries. It is questionable whether this is due to the fact that relatively more autopsies were performed on pedestrians and cyclists. The remaining body regions of the upper and lower extremities play an underpart where the location of severe injuries is concerned. Only with decreasing injury severity, the lower extremities seem to be more frequently represented.

Figure 16 gives an overview over the distribution of the most severely injured parts of the body for persons, who were fatally injured in Lower Saxony in the year 2003 in the course of a traffic accident. This information originates from the public

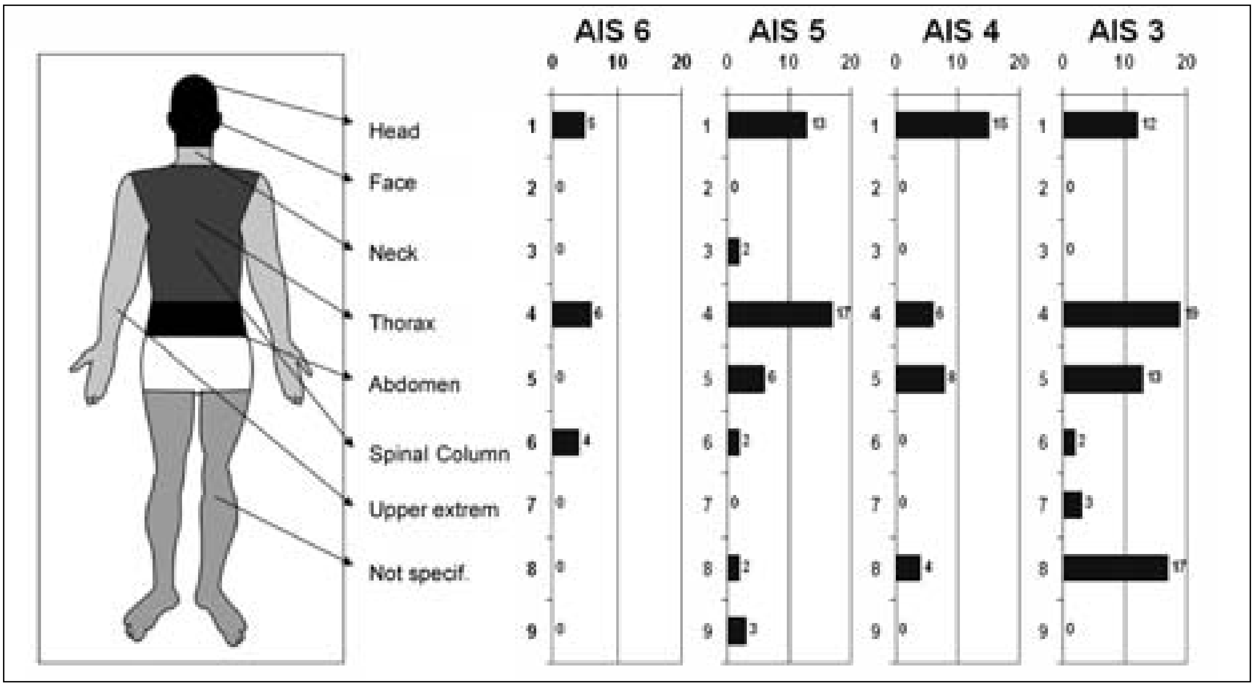


Figure 15: Distribution of the injuries of the 4 most serious degrees of injury severity (AIS 3 to AIS 6) on the corresponding body part

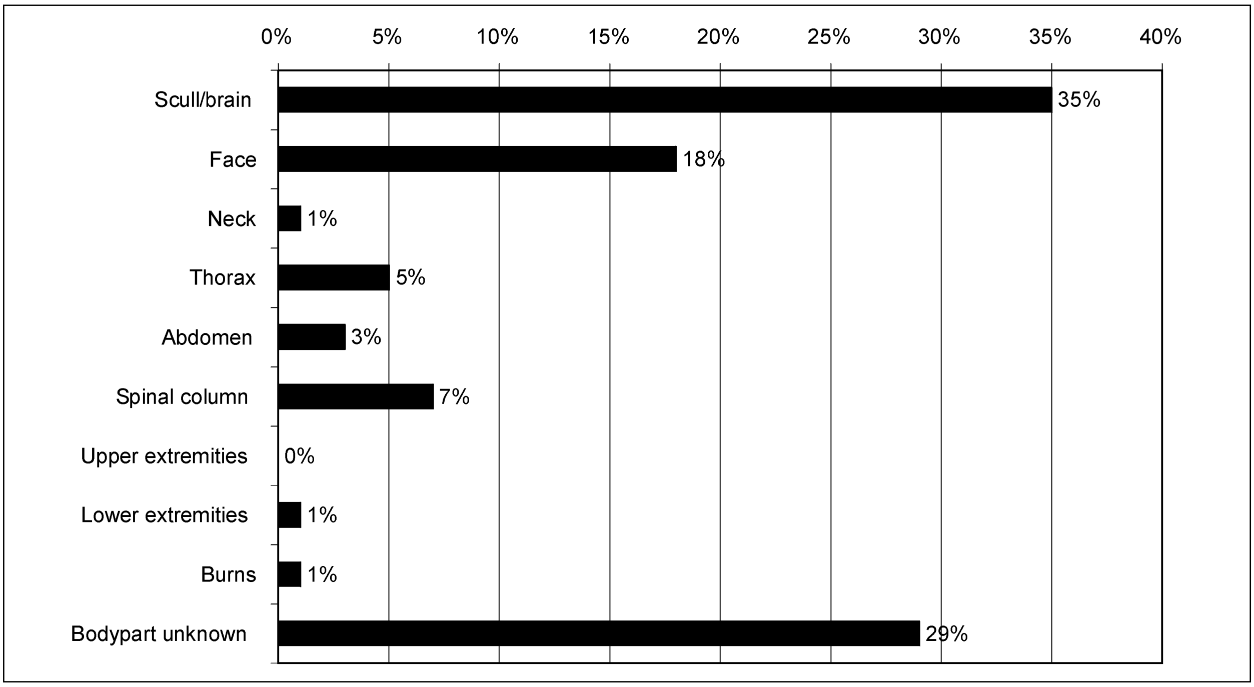


Figure 16: Distribution of the most severely injured body parts of persons fatally injured in traffic accidents in Lower Saxony in 2003

prosecutor's files of inquiry and the physician reports and autopsy reports contained in them. In 12% of all cases such documents were available, in 75% of the cases these could be gleaned from death certificates or police reports, however not in an exhaustive manner. Only for 146 fatalities of altogether 225 in the database containing 202 accidents, the most severely injured body parts could be determined.

It can be read from Figure 16 that injuries of the head are frequently the most severe injuries of traffic fatalities and thus represent the most frequent cause of death for the persons involved in fatal accidents. With the exception of injuries of the spinal column and the thorax the other parts of the body are rather underrepresented.

Conclusion and Discussion

Recapitulatory, it can be stated that the selected methodology of the analysis of traffic accidents based on information from the public prosecutor's files of inquiry offers quite a good base of scientific analysis and data acquisition after conclusion of the forensic procedure. The methodology "Statistical Analysis of Prosecution Accident Cases" is called SAPAC. Such a methodology offers an additional possibility at a justifiable expenditure of scientifically using the collected information of a forensic public prosecutor's preliminary investigation, beyond the possibilities of the statistical accident documentation by means of police reports and the detailed in-depth investigations with very comprehensive and detailed information, concerning vehicle deformation, local accident conditions and injury details, conducted by scientific teams. By the application of the legal framework conditions of data security for scientific use, the possibility of data acquisition and analysis for scientific purposes is given.

In the context of this study, a process of random sampling and a methodical procedure for the scientific use of the public prosecutor's files of inquiry were developed and a data base for the analysis of accidents was established, here using accidents from the German state of Lower Saxony, called FALS (Fatal Accident Data Lower Saxony), in order to determine the accident structure and injury situation of killed road users with SAPAC. In contrast to the analysis of the data of the official statistics, the public prosecutor's files usually contain more comprehensive information concerning the sequence of the accident, the causes as well as the damage and injury patterns.

The study showed that in fatal accidents frequently speed is a parameter substantially affecting the accident. Accidents on state and federal highways constitute the major share (approx. 60%), 80% occurred outside urban areas. Head and thorax injuries are among the most severe injuries.

Occupants of cars were frequently killed in curve accidents, pedestrians while crossing a road away from pedestrian crossings, bicyclists when turning and crossing privileged roads with traffic from the left. Motor cyclists were frequently killed when turning left and colliding with oncoming vehicles. Truck drivers frequently suffered fatal injuries in accidents in longitudinal traffic.

The study showed a good method for extracting information, which is otherwise not possible using the typical national statistics on the basis of the unchanged police reports. With this type of collection on the basis of the files of inquiry of the public prosecutor's offices and courts SAPAC, the average of 160 accident characteristics for each accident are usable. This is a fraction of the information gleaned from large-scale in-depth investigation teams. For example, in GIDAS for each accident about 2000 to 3000 items of information are collected. But the FALS database supplied a good overview of the accident structure and the corresponding injuries. A comprehensive study of the causes of accidents cannot be accomplished on the basis of this information. One is limited to the information given by the police, witnesses and the expert, all of whom are not present to an equal degree in all cases and therefore differ in quantity and quality. The data base permits statements concerning the avoidability of fatal accidents, however. In 8% of the cases, where passenger cars caused the fatal accidents, the accident would have been avoidable, 38,5% of the passenger car drivers that did not cause the accident, could have avoided it. This demonstrates the possibilities of the acquisition of detailed information by means of SAPAC, whose data structure is described in Table 1 in the Annex.

SAPAC can also be used to supply statements concerning the types of head injuries. Thus brain injuries and fractured skulls turned out to have occurred particularly frequently for killed passenger car occupants, which with a larger amount of cases could also be depicted for different collision speeds and EES values (Energy Equivalent Speed). The opportunity of making very detailed evaluations from the database requires breaking the total collective down to few cases for certain questions. Only 1 applicable case emerged, when head injuries of car occupants were known and EES in the case of passenger cars turning left was available. Thus in-depth analyses based on this methodology are limited. This deficit can be met only by increasing the number of cases. It would be sensible in this context to either extend the radius of action to several states or to analyze the data collected for several years, in order to be able to analyze positive and negative developments or trends.

That process of data collection and data analysis from public prosecutor's files of inquiry and court records SAPAC, selected here as a methodical approach, appears sensible and should be continued further. Here the data base FALS (Fatal Accidents Lower Saxony), established using accidents from the year 2003, is available and is scientifically usable.

References

1 H. APPEL, U. WANDERER, J. BLÖDORN: Forschungsbericht Nr. 206, Technische Universität Berlin, im Auftrag der Bundesanstalt für Straßenwesen, 1976

2 E. SCHULLER, G. BEIER: Verletzungsmechanische Fragestellungen bei der Rekonstruktion von Verkehrsunfällen, Kongressbericht der Deutschen Gesellschaft für Verkehrsmedizin e. V. im Auftrag der Bundesanstalt für Straßenwesen, Heft 56, 1986

Annex

General accident data	Traffic lights present	Trailer used	Personal/inury data
Day of week	Road surface type	Alcohol involvement	Seat row
Autopsy report available	Condition of roadway	Blood alcohol level	Seating position
Technical expertise available	Surface contaminants	Drug involvement	Driver y/n
Local area	Construction site present	Drivers licence since	Seatbelt used
Accident category according to the NLS	Bicycle lane/type	Driver is foreigner living in	Ejection from vehicle
Accident type according to the NLS	Lighting conditions	Nationality of driver	Entrapment
Accident category acc. to CARE defin.	Weather conditions	Nationality of veh. license	Person run over
Accident type according to the ISK	Fog present	Is driver owner of vehicle	Age
Accident kind according to the NLS	Visibility	ABS	Sex
Amount of involved cars	Strong winds	ESP	Hight of person
Amount of involved trucks	Transient factors	Vehicle manufact/type code	Weight of person
Amount of involved two-wheelers	Artificial lighting	Vehicle type	Marital status
Amount of involved pedestrians	Traffic calming	Car body style	Occupation
Amount of vehicles damaged	Division of lanes	Amount of doors	Suicide
Amount of involved poeple not injured	Type of crossing	Drive of vehicle	Injury severity
Amount of involved poeple slightly injured	Alignment of roadway	Color of vehicle	Consciosness arrival first aider
Amount of involved poeple heavily injured	Vehicle specific data	Engine power	Taken to hospital
Amount of involved poeple killed	Type of accident participant	ccm	No. of night in hospital
Total damage in EUR	Manufacturer	Vehicle max. speed	Died at scene
Accident with influence of alcohol	Vehicle model	Amount of axles	Days to death
Object struck off road	Amount of occupants	Driven axles	Bodyregion of heaviest injuries
At least one tow-away vehicle	Accident causer according to police	Kerb weight	Injury description
Hit and run	Vehicle movement before accident	Max. permitted weight	AIS-code
Accident with animal involvement	Accident evasion manoeuvre	Year of manufacure	Road user type specific var.
District	Omitted reaction of driver	Age of vehicle	Airbag availability
County	Driving direction before accident	Has veh. passed mand. inspection	Airbag deployment
Community	Collision type	Hazardous cargo	Helmet used
Collision type	Collision angle	Hazardous cargo classification	Reflecting clothing used
Roadway specific data	Amount of collisions	Hazardous cargo discharged	Bicycle lane available
Road classification	Driver/Pedestrian handicapped	Most heaviliy injured occupant	Bicycle lane used
Local area	Hit and run	Place of damage	Direction of collision
Type of road	Accident cause 1 according to NLS	Interacted with	Type of Motorcycle
Driving-direction of accident causer	Accident cause 2 according to NLS	Vehicle catch fire	Helmet type
Type of vincinity	Accident cause 3 according to NLS	Vehicle submersion	Dedicated Motorcycle clothing
Traffic density	Accident avoidable acc. to expertise	Vehicle tow-away vehicle	Helmet lost on accident
Roadway characteristics acc. to NLS	Collision speed according to expertise	3rd column of CDC	Chin strap torn apart
Particularities according to NLS	Speed before accident	Jacknife	
Amount of lanes in incr. direction	EES according to expertise	Vehicle roll over	
Amount of lanes in decr. direction	Object hit off road	Vehicle came to rest on	
Amount of lanes in both directions	Is vehicle defect a cause	Vehicle width	
Speed limit	Reckless driving before accident	Vehicle lenght	
Type of speed limit	Type of vehicle according to NLS	Damage on vehicle in EUR	

Table 1: Variables of FALS Data base

Y.W.R. de Vries
TNO-Automotive Safety, Delft, The Netherlands

N.A. Jongerius
DAF Trucks, Eindhofen, The Netherlands

Method For In-Depth Traffic Accident Case-Control Studies

Abstract

Internationally, the need is expressed for harmonized traffic accident data collection (PSN, PENDANT, etc.). Together with this effort of harmonization, traffic accident investigation moves more and more in the direction of accident causation. As current methods only partly address these needs, a new method was set up. The main characteristics of this method are:

- Accident/injury causation (associated) factors can objectively be identified and quantified, by comparison with exposure information from a normal population.
- All relevant accident and exposure data can be included: human-, vehicle-, and environmental related data for the pre-crash, crash and post-crash situation (the so-called Haddon matrix). The level of detail can be chosen depending on interest and/or budget, which makes the method very flexible.

In this paper the accident collection and control group method are presented, including some of the achieved results from a pilot study on 30 truck accidents and 30 control locations. The data were analyzed by using cross-tabulations and classification-tree analysis. The method proved useful for the identification of statistically significant causational aspects.

Notation

N Number of virtual accidents

n_m Number of vehicles in main direction

n_o Number of vehicles in other directions

γ Environmental impact

M Maximum number of virtual impacts (set at 10.000)

A_m Allowed number of vehicles in the main direction

A_o Allowed number of vehicles in the other directions

N_i^A Number of vehicles of type *i* in the maximum allowed sample

N_i^V Number of vehicles of type *i* in the video sample of duration *D*

D Video duration in minutes

W_i Weight factor for vehicles of type *i*

W_{ij}^I Weight factor for the impact between vehicles of type *i* and *j*

L_k Available percentage of road type *i*

N_k^s Number of locations sampled for road type *i*

W_k^L Weight factor for the location *i*

Introduction

Traffic accident investigation is used more and more to address all cells of the Haddon-matrix (see Figure 1). The information from this matrix is used to deploy new activities in relevant areas.

Knowledge on primary safety and pre-crash aspects (i.e. avoiding accidents) requires information about accident causation. Data bases and methods that have been developed for accident causation studies (e.g. EACS, ETAC) up till now, belong to the case-series studies: cases are investigated and frequency counts give information on occurrence of possible risk factors in these accidents. The impossibility to relate these occurrences to reference data is a large drawback as will be shown later.

A new method has been set up, with the main aim to address the afore mentioned limitation. The main objectives of this paper are to discuss the principles of this newly developed method for an epidemiological study into accident causation, and to show the results of a first pilot analysis on truck accidents.

The work has been carried out by TNO, with the support from DAF Trucks, Scania Trucks, and the Dutch Ministry of Transport, Public Works and Water Management and the Dutch Ministry of Economic Affairs.

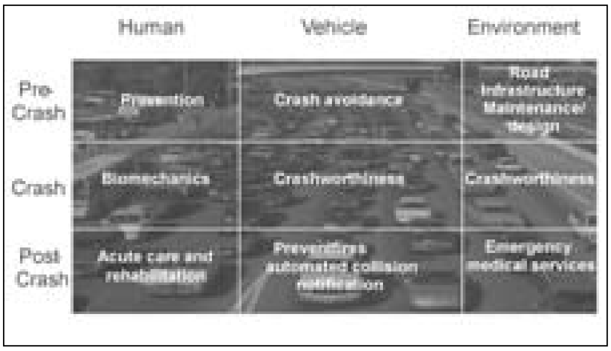


Figure 1: Example of the Haddon matrix

Exposure

Correct information about the cause(s) of accidents is relevant for policy makers and vehicle manufacturers. Identification of accident causes requires the acquisition of large amounts of data per accident, and a correct interpretation of this data (accident reconstruction, etc.).

Incorrect knowledge on accident causes may lead to the implementation of non-effective countermeasures. Such incorrect knowledge may be due to exposure effects or subjective assessment by investigators. High frequencies do not necessarily indicate a risk, but also show the amount of exposure. The investigator's subjectivity can originate from pre-determined ideas and feelings about what the normal operation should be under certain circumstances. These ideas are not necessarily correct and may lead to misjudgments. Therefore some kind of reference data is needed to correctly identify risk factors. A literature survey was carried out to find previously used study setups which made use of reference data. Possibilities for obtaining such observational data are the following:

Internal control groups
Internal control groups are groups of accidents for which a specific parameter is assumed not to have any influence. Differences in the presence or absence of the parameter in the studied group and the control group can indicate a relationship with accident occurrence. Two main problems exist: many cases have to be present and it has to be sure that the parameter under study has no effect in the control group.

Global indicators
Sometimes global indicators (kilometers driven, etc.) are used as reference data to indicate potential problems. However, the results are very dependent on the indicator that is used [ELSEVIER, 1997] and can be tuned with the use of an indicator which provides the results that are wanted. Furthermore, global indicators can not go into the detail needed for accident causation research (e.g. type of use).

Cohort study
Because traffic accidents have a relatively low occurrence, cohort studies are inefficient. Z group of drivers should be followed for a certain period. During this period some accidents should occur in this group. Drivers with and without accidents can be compared. The presence of accidents in this group is expected to be quite low when the group is not very large or the study duration is not very long.

Case-control study
When a case-series study is extended with the collection of some sort of control group, which can be used as reference data a case-control study design is obtained, from which associations between factors can be obtained.

Because in-depth research is already a case-series study, extension to a case-control study is therefore the most logical approach. A recent example is the European Motorcycle Accident In-Depth Study (MAIDS) [OECD, 1999], carried out in five countries, in which drivers were interviewed at gas stations. Another option sometimes used is to question drivers passing through the same scene one week after the accident. In both cases analysis on environmental factors was not possible because of the chosen method. Driver cooperation was also a problematic issue. However, both methods served as a basis for the newly developed method presented in this paper.

Method

Virtual accidents

In order to compare accidents directly with exposure information in a case-control study, the data need to be in the same format. Therefore one would like to obtain the control group from normal traffic situations, which can directly be compared with the accidents: some kind of "virtual accident" (every accident that could have occurred). Traffic intensity can be used as a measure. The number of "virtual accidents" for a given location can then be calculated by:

$$N = n_m \left((n_m - 1) + n_o + \gamma \right) \quad [1]$$

Each target vehicle (in this study a truck) has a virtual accident with every other vehicle passing through the scene. The number of virtual impacts is therewith frequency induced. The more other vehicles are present, the more virtual impacts. Each vehicle can have an impact with a vehicle in the same direction as well as with a vehicle from another direction or with an environmental object (see formula [1]). Environmental information of the location has to be coded with the virtual accident. The total of all virtual impacts in all monitored traffic situations will then serve as the control group.

A main problem with the virtual impact method is that the number of impacts increases quadratically with each extra vehicle in the main stream. Therefore the number of generated virtual impacts is limited to ten thousand per location. The maximum allowed number of vehicles for this maximum number of virtual impacts that has to be sampled for the main stream (A_m) and the other directions (A_o) is calculated according to formula [2].

$$f = \frac{n_m}{n_o} = \frac{A_m}{A_o}$$
$$M = A_m \cdot \left((A_m - 1) + A_o + \gamma \right) \Rightarrow$$
$$A_m = \sqrt{\tfrac{f}{f+1} M} \qquad [2]$$

This maximum allowed number of vehicles is sampled randomly from the video sample to acquire the distribution of vehicle types on a specific location.

Interaction model

In practice the traffic system is rather complex. Driver, vehicle and environment interact in unknown ways (see Figure 2a). All information needed for the control group should therefore be investigated at the same time.

The “virtual accidents” have to be collected in the same area in which the accidents are collected and should represent the normal traffic situations in that area. Therefore, the inspection of the locations should be completely randomized over the research area, such that it represents the conditions in the accident collection area. The samples should be taken equally over the duration of the study and at random times. The method for sampling the locations is shown later.

The traffic counts can be obtained from video, together with driven speeds, manoeuvers, distances to other road users, color, etc. Extra information can be obtained by license plate detection, coupled with vehicle registration information. From all the vehicles passing through the location the drivers should be observed and interviewed, and the vehicles should be inspected similar to the accidents investigations. This imposes a practical problem, because not all drivers can be stopped and interviewed in a monitored scene. Even if a sample could be taken, this means that needs to be on an involuntary bases, otherwise biases are introduced. In many occasions this is not possible. However, there is a way around this when some conditions and assumptions are met.

Model assumptions

Two possibilities now arise. For (semi) permanent physical conditions for which we expect that they have no relation with the environmental conditions (e.g. gender, illness, etc.) a control group could be gathered at any given location, because the conditions will be randomly distributed over the environment (not necessarily over the vehicles). Transient conditions which may have an interaction with or are induced by the environment are more complicated (attention diversion, using cruise control on motorways). Non-environment related issues can be investigated by interviewing people about the frequency of use or habits. Environmentally related habits can also be investigated on a more global level by asking about frequency of use under specific circumstances. This method suffers (less) from the same problems as global indicators (see Exposure).

The other option could be to form a cohort of random drivers whose behavior is recorded/logged under occurring circumstances. This option is more complicated and time consuming, but the result is likely better. For financial reasons the interviewing method is chosen for this study.

The driver information will be obtained at convenient locations which are sufficiently randomized. Drivers are interviewed and vehicles inspected.

The idea that is now used is the following (see Figure 2b): The driver interviews and detailed vehicle inspections are treated as missing values in the data from the video observations. These missing data are imputed from the separate vehicle inspections and interviews on the video information. The random imputation is conditioned (matched) on variables collected in both inspections (so-called conditional random imputation). These values may not be treated as real values per accident but can be used to make appropriate inferences and to show statistical associations. The vehicle type distribution does not have to match the one found from the video observations and can deliberately be biased towards groups of interest to obtain the most useful information. The parameter for which the bias is introduced should also be measured from the video data (vehicle type, color, etc.). It would not lead to a biased sample, because the distribution of generated virtual accidents would stay the same, only with more or less details and statistical certainty for specific groups.

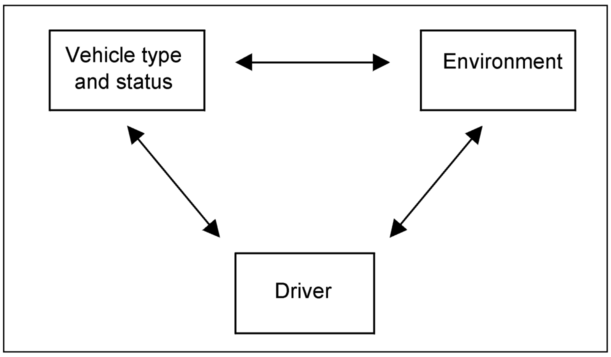


Figure 2a: Main interactions

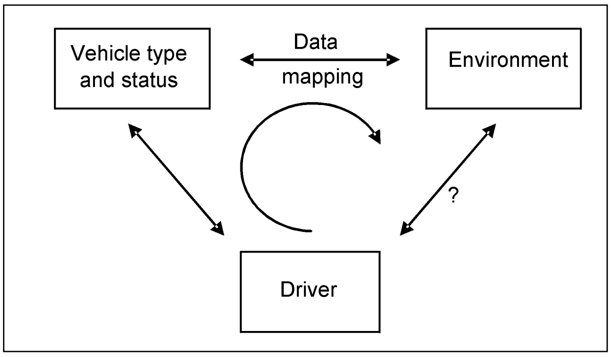


Figure 2b: Model assumptions and imputation

In future projects multiple imputation techniques can be used in order to improve the prediction of the missing values [RUBIN, 1987]. For this pilot study this method has not been used yet.

Practical Implementation

Selection of randomized locations

Information on all Dutch roads is available from a Geographic Information System (GIS) database (see Figure 3). Most other countries also have mapped their (main) roads into vector based files that are compatible with GIS [GIS, 2004]. The location selection has been split into crossings and segments without crossings. In order to sample all roads equally, all segments have been divided into 25 meter sections. Sampling the number of lanes instead of the number of roads is more appropriate, so that the traffic flow on one-way streets and multiple-lane streets are sampled just as much as on two-way streets.

For crossings the following approach is taken: Each lane into the crossing is counted as an intersection, because vehicles may come from all directions. Roundabouts are considered to be sets of T-crossings with two in-coming lanes and one out-going lane. This is the same as considering it to be one crossing, due to the fact that the number of manoeuvers is limited in the multiple T-crossing approach.

Figure 3: Example of a GIS-location and the low visibility video pole clamped to a lamp-post

A (disproportionate) stratified sampling plan may be used if specific road types are of more interest to the researcher. For this study stratification was used. The road types that were expected to have a higher accident occurrence, were sampled with higher frequency to obtain more detail for those roads.

Obtaining the control group information

In Figure 4 the workflow is depicted. Traffic lanes are randomly selected in the accident collection region and will serve as the main traffic streams. All lanes and the scenes are recorded on video for approximately 30 minutes from a high location (a low visibility extendable beam; see Figure 3) to reduce parallax effects in the analysis of speeds and distances. With special developed software and markings on the road with known distance to each other, the speed and distance to other vehicles can be obtained from the video. For trucks extra information is recorded that will improve the conditioning (matching) for the required conditional random imputation.

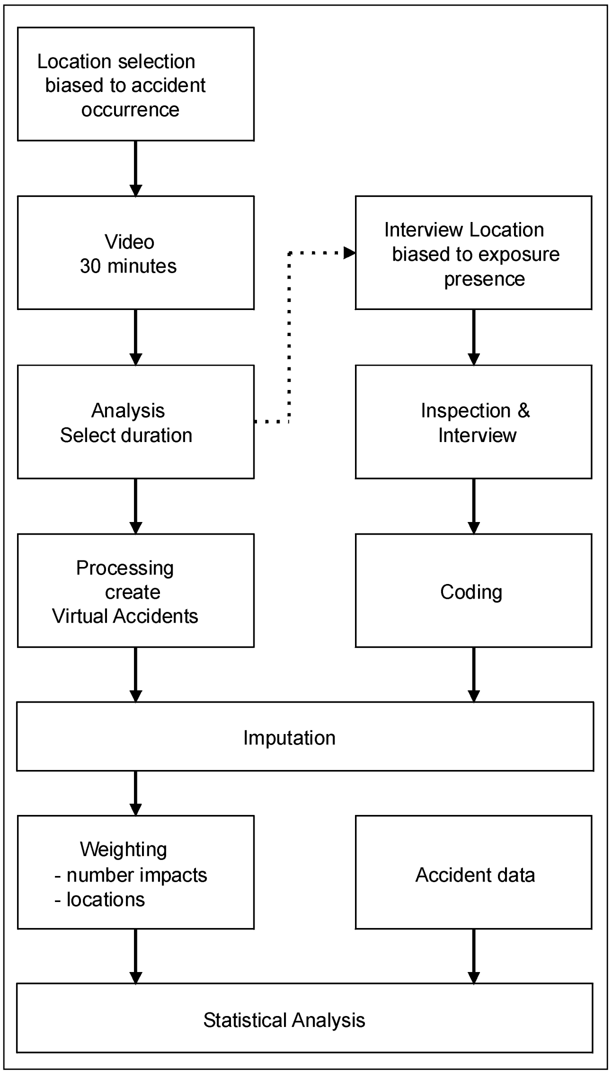


Figure 4: Work flow diagram

The interviews were done at restaurants, gas stations, distribution centers and companies using (specific) trucks. The selection of truck types was matched to the distribution observed in the accident sample, again to obtain a maximum of detail with minimum effort. In doing so, a bias was introduced in the interviews. This only results in a larger sample with a higher confidence level for the vehicles of interest, and less certain information for the other vehicles. A comparison will have to be made between accident trucks of the same type (e.g. on mirror adjustments) in the analysis, for which a sample with higher confidence level is beneficial. Not all truck types could be investigated with the limited sample.

Data weighting

A problem which manifested itself is that due to several reasons the video duration of 30 minutes was in more than one occasion not 30 minutes. Another aspect is that analyzing 30 minutes of motorway video is time consuming and not really necessary to obtain a stable distribution. Thirdly, the number of virtual impacts that are created is limited. Therefore a sample of the video is taken. This made it necessary to assign a weight factor to each vehicle according to the following formula:

$$W_i = \frac{N_i^V}{N_i^A} \cdot \frac{30}{D} \qquad [3]$$

The sum of vehicles of type i in the maximum allowed sample (N_i^A) equals the sum of the allowed number of vehicles from formula [2]:

$$\sum_i N_i^A = A_m + A_o \qquad [4]$$

The weight factor for each virtual impact dependents on the involved vehicles and was established in the following way:

$$W_{ij}^{\ I} = W_i \cdot W_j \qquad [5]$$

After establishing these weight factors per vehicle and virtual impact on a given location, the locations had to be weighted towards their real presence in the sampling region:

$$W_k{}^L = \frac{L_k}{N_k{}^s}$$

$$W_{ijk}{}^{LI} = \left(W_{ij}{}^I\right)_k \cdot W_k{}^L$$

$$W_{ik}{}^{LV} = \left(W_i^V\right)_k \cdot W_k{}^L \qquad [6]$$

These weight factors were used throughout the analysis.

Results

The authors want to stress that the results presented in the following sections can only serve as an indication and merely show the analysis possibilities because the sample of accidents is limited.

Accidents and control group population

For this study 30 truck accidents were investigated. The Dutch Accident Research Team (DART) was notified by the technical police departments in the province of Zuid-Holland. The technical police departments in these regions are notified of all truck accidents and measure accident (skid) marks in detail. All accidents for which TNO was notified were investigated by the investigation team. The total sample is biased towards more severe accidents. Comparison with the control group therefore gives information about severe accidents.

Of these accidents, 15 occurred on straight segments and 15 on crossings. The road types (urban, motorway, etc.) of the control group population were matched with the accident occurrence road types and weighted afterwards to obtain a maximum of accuracy and detail.

Example analysis

In Table 1 the frequencies of collision partners in the accident cases and in the virtual accidents (control) on intersections are shown. The adjusted residuals indicate whether the cases and controls differ significantly and may be interpreted as follows: an absolute value larger than two indicates for normal distributions a 95% certainty that a significant difference is present [SPSS, 1998]. The sample in this pilot-study is unfortunately too small to satisfy the condition of normality, therefore only indications can be given. From the presented table it can be read that motorized two-wheelers and bicycles are more present in the accident cases than in the control group. If the sample were large enough, this would indicate that the probability to be in an accident as a bicyclist or motorized two-wheeler is higher than for example a car driver.

A classification tree analysis [SPSS, 1998] with a forced split on vulnerable road users (motorized two-wheelers, bicycles and pedestrians) was used to identify aspects in truck-vulnerable road user impacts, which were found to have a high probability of occurrence (see Appendix). The variables in the classification tree were the manoeuvers of the truck and vulnerable road user with respect to each other.

Compared with the virtual truck accidents (frequency of occurrence of normal meetings) with vulnerable road users (VRU) two groups can be identified with differences in occurrence:

- Truck turning right, with the original driving direction identical to the VRU driving direction. This situation was never observed in the virtual accidents. Not shown is that this occurs in all investigated cases on local small roads and that the VRU is going straight or is turning right. This

			Case		
			Case	Control	Total
OV1: Object type	Truck	Count	0	14158	14158
		% within Case	.0%	6.6%	6.6%
		Adjusted Residual	-1.0	1.0	
	Car	Count	3	170786	170789
		% within Case	20.0%	79.6%	79.6%
		Adjusted Residual	-5.7	5.7	
	Motorised 2-wheeler	Count	3	354	357
		% within Case	20.0%	.2%	.2%
		Adjusted Residual	18.8	-18.8	
	Bicycle	Count	6	1008	1014
		% within Case	40.0%	.5%	.5%
		Adjusted Residual	22.3	-22.3	
	Bus	Count	1	3145	3146
		% within Case	6.7%	1.5%	1.5%
		Adjusted Residual	1.7	-1.7	
	Van	Count	1	24900	24901
		% within Case	6.7%	11.6%	11.6%
		Adjusted Residual	-.6	.6	
	Other vehicle	Count	0	8	8
		% within Case	.0%	.0%	.0%
		Adjusted Residual	.0	.0	
	Pedestrian	Count	0	12	12
		% within Case	.0%	.0%	.0%
		Adjusted Residual	.0	.0	
	Stationary object	Count	1	166	167
		% within Case	6.7%	.1%	.1%
		Adjusted Residual	9.2	-9.2	
Total		Count	15	214537	214552
		% within Case	100.0%	100.0%	100.0%

a. Junction = Yes

Table 1: Comparison between collision partners in accident cases and in virtual accidents on intersections (The distributions differ significantly. Chi^2-test: $p<0.05$). Cases represent accidents and controls represent virtual accidents

is typically the situation in which blind angle aspects are considered relevant.

- Truck is going in the opposite direction from where it comes from (driving backwards); while in the control group this situation is never observed. This is possibly also a blind angle aspect, but on the rear of the truck.

Discussion

On the method

An aspect that is more difficult to investigate with this study setup is the environmentally related driver behavior: whether an association exists between certain driver behavior and the environment (e.g. cruise control on motorways, use of mirrors at certain locations). When it is expected that these factors play an important role, the relationship can be investigated by implementing questions regarding these relationships in the interviews. Frequency of use under various conditions can be asked. Another more expensive method already mentioned is to form a cohort of random drivers for which the behavior and actions are recorded in some way, possibly by actually monitoring the driver and recording and coding the behavior. Again it is not required that the population matches the exposure information from video.

Night time control samples caused some problems. Video information with “night shot”-mode was not of very good quality.

On the results

From the classification tree in the Appendix it can be seen that right turning trucks and VRU’s coming from the same direction have a relatively high number of cases (3) with respect to the control group (0). At the top of the classification tree this was (10 cases/ 250 controls). However, many more virtual bicycle accidents would have been present if due to chance a location near a school was sampled in the small control group or sampled at hours at which children and students bike to school. Therefore no real conclusions may be drawn from this sample. When the sample would have been large enough and the same situation would persist it might have been concluded for these cases that situations with right turning trucks and VRU’s coming from the same direction impose a greater accident probability than other cases. It then could be suggested that this relates to blind angle aspects.

With more cases the classification tree analysis could go further. If any control group cases would be present for these typically dangerous situations a comparison between environmental, driver or truck-related issues could be made to show typical problems for these locations. But at this time, no control data is available and the number of accidents is clearly limited.

Although potentially influenced by the coincidental choice of control locations, the method of analysis seems to indicate a potential risk factor that was also identified in national statistics [de VRIES, 2000]. The conclusions from the national statistics were based on assumptions about exposure. This in-depth analysis shows that this can be supported objectively with control-group information. Details concerning mirror adjustment, road layout can give more details about exact causation-related aspects. Again comparison with control group information can show discrepancies between the two data sets. This information can be further supported by objective and subjective descriptive information.

Risk adaptation and secondary safety

This method could also identify certain driver behavior and driver risk assessment. The exposure data and injury probability data can be used to calculate driver risk, the risk a driver “feels”:

Relative risk (*K* in accident type)=
P (*K*| accident type) χ *P* (accient type) [7]

The relative risk for being killed (*K*) in a certain accident type equals the probability to get killed in a certain accident type times the probability that such an accident occurs. The relative probability for occurrence can be obtained from the exposure data. If this occurrence probability is very low, but the consequences still high, a driver might still feel quite safe. When the occurrence probability is high and the probability is also high this will be perceived as dangerous.

A certain safety feature could induce more-unsafe driving (risk adaptation). Exposure data can show that this may be the case if discrepancies exist between the accidents population and the exposure population in the presence of secondary safety features. Suppose the degree of implementation in the normal population of a secondary safety feature is found to be 50% (e.g. frontal airbag), one would expect to find a same or less relative accident probability (number of accidents divided by the number of virtual accidents in that category) for cars equipped and cars not equipped with airbag. Airbags are supposed to reduce injuries, so some accidents will not be reported to the police anymore or will not be included in the study sample, therefore a lower accident probability is expected. If one would find a higher accident probability for cars equipped with airbags, but still a lower probability to get injured one may conclude that risk adaptation has occurred, reducing the expected benefit. Measuring the degree of implementation based on for example car sell rates or kilometers driven should be done only with extreme care (see Introduction).

Conclusions

From the literature study it was learned that a case-control study is best suited for in-depth traffic accident research at this time. No good documented case-control study could be found which includes environmental, driver and vehicle information. Therefore the new method was developed.

- A case-control group study with real and “virtual accidents” was developed and tested on 30 accident cases and 30 random locations.
- Data imputation could technically be realized. A validation was not yet possible because of the small sample.
- Injury causation analysis can be done in great detail. A large amount of data analysis possibilities exist. The analysis possibilities seem to give good information and indications to find problems in accident and injury causation from which new solutions may be derived.
- Risk adaptation for primary and secondary safety features can be assessed.
- Environmental, human and vehicle factors can be investigated together, taking into account the relationship between the factors.
- The results from this study, although limited, are in line with results from other studies.

Recommendations

When defining measures for improved safety, it is recommended to include a dedicated exposure evaluation in order to determine with statistical significance whether, and up to what extent, actual safety improvements can be expected. The case control method presented here is a good approach.

The exposure method should be evaluated on a wider scale, preferably European-wide to effectively indicate risk factors. European projects like SafetyNet or TRACE might provide a good basis.

References

S.L. BANGDIWALA (2000): Methodological Considerations in the Analysis of Injury Data: A challenge for the Injury Research Community, Injury Prevention and Control, Taulor & Francis, ISBN 0-748-40959-9.

DOT (2005): http://www.minvenw.nl/dgg/dodehoek/Zichtveldprobleem/Feitenencijfers/#feiten

ELSEVIER (1997): De kans op een ongeluk, 6-9-1997

GIS (2004): http://www.gis.com/whatisgis/index.html

OECD (2001): Motorcycles: Common international methodology for in-depth accident investigations

D.B. RUBIN (1987): Multiple imputation for non-response in surveys, John Wiley & Sons, New York.

SPSS (1998): AnswerTree 2.0 user’s Guide, ISBN 1-56827-254-5

Y.W.R de VRIES (2000): Accident analysis of heavy trucks, TNO Report, 00.OR.BV.053.1/YdV

Y.W.R de VRIES (2005): A method for control group data to find accident and injury causation factors in in-depth traffic accident studies, TNO Report, 05.OR.SA.034.1/YdV

Appendix

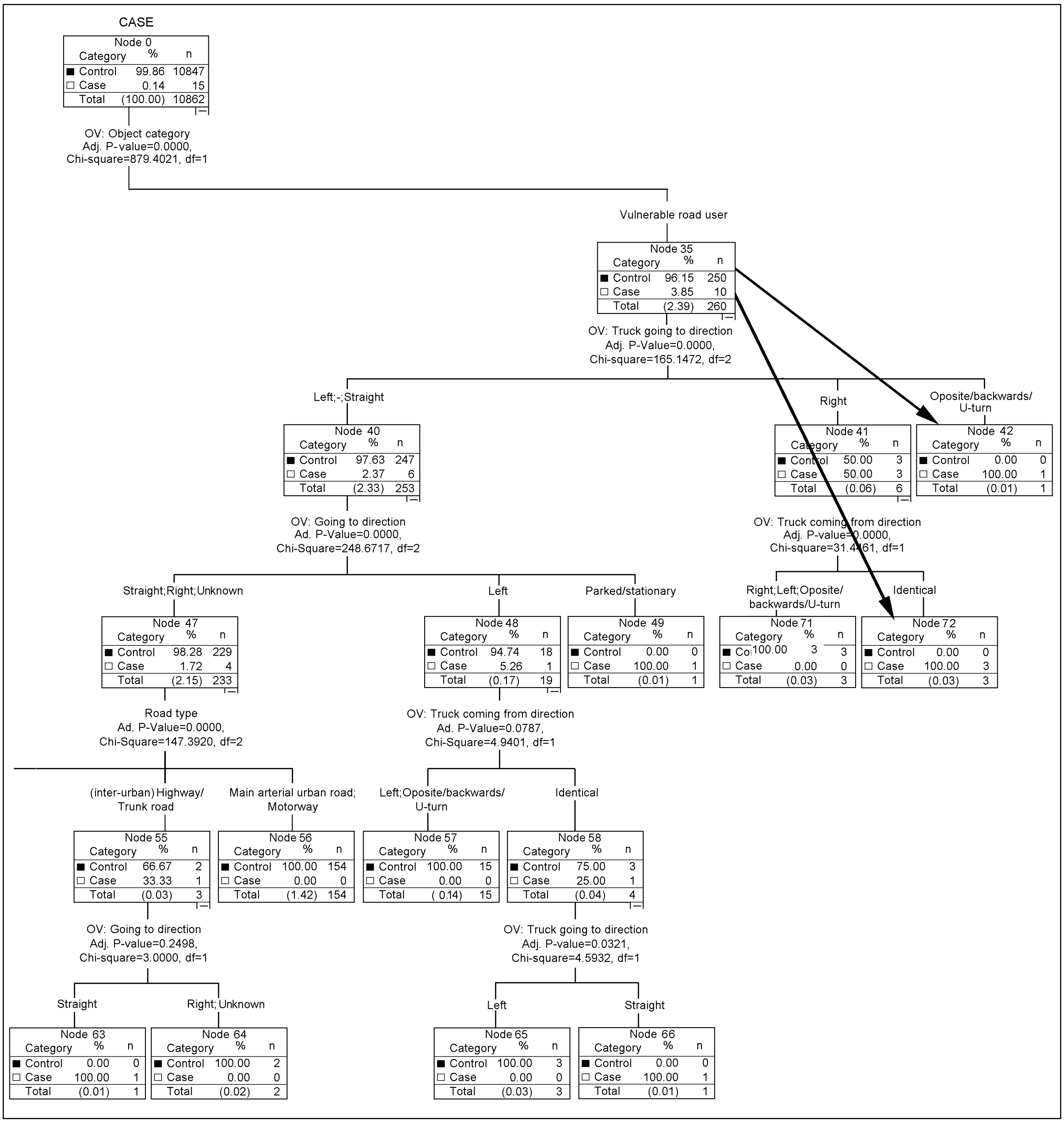


Figure 5: Classification tree. Explanation of the used terminology: underneath vulnerable road users: from the Other Vehicle (OV) perspective, the truck is going into a certain direction relative to the OV. Suppose the truck is turning right, then read: from the OV perspective the truck is coming from, e.g., the identical direction as the OV

Session:
Special Topics for Vulnerable Road Users

J. König, F.A. Berg

S.N. Huang, J.K. Yang, F. Eklund

C. Haasper, D. Otte, L. Knobloch, C. Probst, C. Krettek, M. Richter

J. König, F.A. Berg
DEKRA Automobil GmbH, Accident Research and Crash Test Center, Stuttgart, Germany

Powered Two-Wheeler Accidents – First Results of APROSYS SP 4 Implying GIDAS 2002 Data

Abstract

In recent years special attention has been paid to reducing the number of fatalities resulting from road traffic accidents. The ambitious target to cut in half the number of road users who are killed each year by 2010 compared with the 2001 figures, as set out in the European White Paper "European Transport Policy for 2010: Time to Decide" implies a general approach covering all kinds of road users. Much has been achieved, e.g. in relation to the safety of car passengers and pedestrians but PTW accidents still represent a significant proportion of fatal road accidents. More than 6,000 motorcyclists die annually on European roads which amounts to 16% of the EU-15 road fatalities. The European Commission therefore launched in 2004 a Sub-Project dealing with motorcycle accidents within an Integrated Project called APROSYS (Advanced PROtection SYStems) forming part of the 6th Framework Programme. In a first step, the combined national statistical data collections of Germany, Italy, the Netherlands and Spain were analysed. Amongst other things parameters like accident location, road conditions, road alignment and injury severity have been explored. The main focus of the analysis was on serious and fatal motorcycle accidents and the results showed similar trends in all four countries. From these results 7 accident scenarios were selected for further investigation via such in-depth databases as the DEKRA database, the GIDAS 2002 database, the COST 327 database and the Dutch element of the MAIDS database. Three tasks, namely the study of PTW collisions with passenger cars, PTW accidents involving road infrastructure features, and motorcyclist protective devices have been assessed and these will concentrate inter alia on accident causes, rider kinematics and injury patterns. A detailed literature review together with the findings of the in-depths database analysis is presented in the paper. Conclusions are drawn and the further stages of the project are highlighted.

Notation

IP	Integrated Project
SP	Sub-Project
PTW	Powered Two-Wheeler
WP	Work-package
AIS	Abbreviated Injury Scale

Introduction

More than 6,000 of the 40,000 fatalities on European roads in 2001 were related to powered two-wheelers (PTWs). Compared to the overall number of victims on the roads, this figure represents 15% of the toll of this dreadful aspect of our society. The European Commission has launched the 3rd European Road Safety Action Plan with the ambitious goal of reducing the fatalities by 50% by 2010. By 2025, it is intended that the number of persons killed or severely injured on the road each year shall be reduced by 75% compared with 2001. Against this background the EC launched the Integrated Project APROSYS (Advanced PROtection SYStems) within its 6th Framework Programme The APROSYS Integrated Project on Advanced Protective Systems is focussed on scientific and technology development in the field of passive safety. It concerns, in particular, human biomechanics, vehicle and infrastructure crashworthiness and occupant and road user protection systems. World-wide, vehicle safety experts agree that significant further reductions in fatalities and injuries can be achieved by using passive safety strategies. APROSYS aims to offer a significant contribution to the reduction of road victims in Europe. In other words, the general objective of the IP is the development and introduction of critical technologies that improve passive safety for all European road users in all relevant accident types and over all ranges of accident severity. Measures and strategies for powered two-wheelers are included within Sub-Project 4 dealing with motorcycle accidents. The purpose of this SP is to reduce the number and severity of user injuries associated with PTWs (including mofa/moped) for the most relevant accident types. This will be achieved by means of in-depth analysis of the different accident scenarios in which motorcyclists were involved (WP1). Interest is to be concentrated on "forgiving" types of road infrastructure features and design (WP2) and advanced protection systems for motorcyclists (WP3). As a first step within the context of WP1, data from various national statistical offices have been analysed. This included SP consortium data from Italy, Germany, Spain and the Netherlands.

National Statistics Analysis

Except for Italy the data from four different countries have been analysed for the years 2000 to 2002 [1]. In the case of Italy the years 1999 to 2001 were chosen because no data were available for 2002. For each country, the differences in data acquisition methods and database restrictions are described prior to the analysis. Therefore a comprehensive understanding of the results as well as of the limiting factors has been gained. A separation of the PTWs into mofa/moped and motorcycles has been made in order to highlight possible differences for the selected variables. A general summary of the PTW situation for the country concerned is followed by an analysis of the population characteristics such as gender and age patterns. The accident circumstances were split into area, time, month, road alignment, road conditions, weather and light conditions. Urban and non-urban areas have been separated. A more precise differentiation of the non-urban roads into highway and other roads has been made. As for the selection of the accident scenarios, which are further addressed in the following work-packages, the focus was on four main variables such as type of vehicle (mofa/moped or motorcycle), type of accident (single vehicle accident or various vehicles involved), type of road alignment (straight, bend, curve, etc.) and area (urban, non-urban). These variables have been cross-linked in order to obtain the different accident scenarios. The figures taken into account for the scenario definition focused only on severe and fatal accidents.

Italy

The analysis was carried out using the Italian accident database owned by the Italian Institute of Statistics (ISTAD) in which only accidents involving at least one injured person are included. It is not possible to distinguish between slight and severe injuries. Moreover, conclusions regarding helmet use cannot be drawn.

In Italy an increasing trend in the number of licensed PTWs is observable. Whereas the moped population remained almost constant, the number of motorcycles rose significantly from 2,967,906 in the year 1999 to 3,729,890 in the year 2001. The PTW group covers 21% of all licensed vehicles in the country. A powered two-wheeler was involved in 35% of all accidents in Italy while for 25% of all casualties at least one PTW was involved. In total, 235,409 accidents with personal injury were recorded in the year 2001, of which 82,451 were PTW accidents. As far as age groups are concerned, in urban and non-urban areas the group of drivers aged 26-35 years is the most significant one in terms of fatal motorcycle accidents and in urban areas the moped drivers aged 18-25 years are mostly involved in accidents resulting in injured persons. Regarding gender, the number of female PTW driver casualties is noteworthy, amounting to some 19%. It is worthy of mention that most fatal accidents involving both mofa/mopeds and motorcycles occur inside urban areas. This is also consistent with other recent studies, which reveal that Italy, Portugal and Greece are the only EC-countries where more fatal PTW accidents are recorded inside than outside urban areas [2]. In that context the vast mofa/moped population is a highly significant factor. The time of day when most accidents happen is between 6 p.m. and 8 p.m. and, as expected, the major proportion of those accidents happens in the summer period. As anticipated, the passenger car is the most frequent collision partner within PTW accidents in urban as well as in non-urban areas which occur on straight roads, intersections and bends. In terms of run-off-the-road accidents on straight roads and intersections, in most cases the kerb is hit, whereas on curves and bends ditches and safety barriers are the objects most frequently hit on rural roads.

Germany

The legal basis for compiling the data is the law and the Statistics of Road Traffic Accidents. Pursuant to this the Federal Statistics are compiled each year from accidents involving vehicular traffic on public roads or places, complete with the number of persons killed or injured and any material damage. According to the relevant law, the police authorities whose officers attended the accident are obliged to submit the report. This implies that the statistics cover only those accidents which were reported to the police. These are primarily accidents with serious consequences. To a relatively large extent, traffic accidents involving only material damage or slight personal injuries are not reported to the police. Since only aggregated data rather than raw data are available in the published yearbooks, some queries could only be pursued to a limited extent. Persons killed are defined as those persons who died within 30 days as a result of the accident, while seriously injured persons are defined as all those who were immediately taken to hospital for inpatient treatment (lasting over a period of at least 24 hours). The data review period covered the years 2000 to 2002.

Because the absolute numbers of killed and injured riders of PTWs since the early 1990s are more or less constant, the relative proportion they represent of the still decreasing number of all victims of road accidents in Germany shows a rising trend. Taking into account that e.g. the share of pedestrians killed in Germany over the years 1980 to 2003 decreased continuously, an increase in the proportion of the users of powered two-wheelers killed over the years 1992 (11.1%) to 2003 (16.6%) is noticeable, Figure 1. As far as the number of injured traffic participants in Germany is concerned, an upward trend in the share of the powered two-wheeler riders injured is also apparent.

In the year 2002 some 54 million licensed vehicles were on German roads and 9% of these were powered two-wheelers. The number of licensed PTWs has remained almost constant in recent years. In respect of all traffic accidents in Germany the involvement of PTWs plays a significant role. A powered two-wheeler is involved in more than 15% of all fatal and 18% of all severe accidents. In the years 2000–2002 most moped casualties were in the age group 18-25. Regarding motorcyclists alone, a shift from the age group 25-35 to the age group 35-45 is observable as far as number of casualties is concerned. This is true for both urban and non-urban traffic accidents where the PTW drivers involved are predominantly of male gender. Most PTW accidents occur inside urban areas. Within these road category statistics the most frequent injury level is the slight injury. As distinct from the motorcycle accidents where only 20% of the accidents with fatal injuries occur inside urban areas, the proportion of fatally injured mofa/moped riders inside urban areas is nearly 50%. Noteworthy is the fact that as far as motorcyclists are concerned the category of highway accidents associated with (mostly) elevated travel speeds is of minor significance in terms of the number of fatally injured PTW riders in general. Most of the

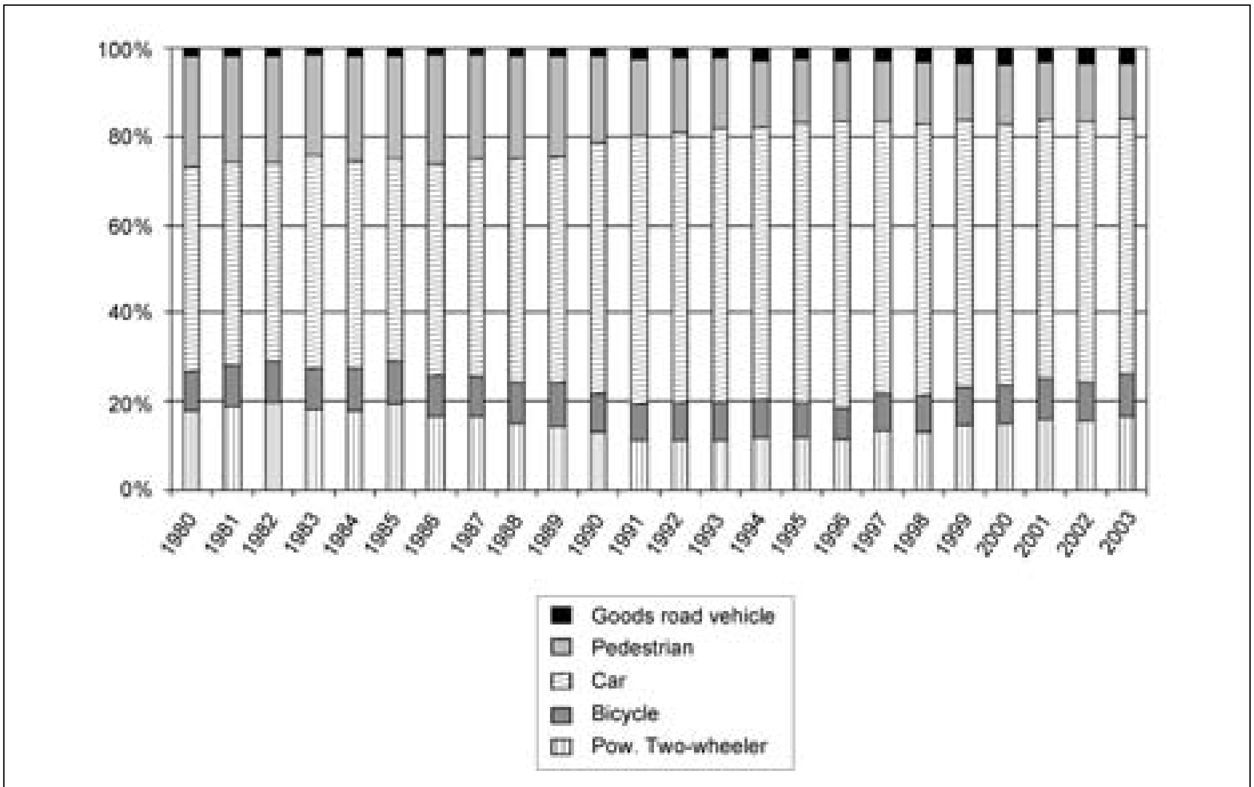


Figure 1: Time history of the specific shares of killed road users among each other in Germany for the period 1980 to 2003

PTW traffic accidents resulting in personal injuries take place in the period from spring to autumn. An observable small gap in July is related to the summer holidays in Germany. PTW accidents happen mostly in dry weather conditions, related to the fact that motorcycle riding is often a leisure activity. Wet and snowy/icy weather conditions are of interest regarding mofa/moped accidents. Here, mofa and mopeds are a common means of travel inside urban areas to go to work. Most PTW accidents take place in the daytime. A particular correlation between light conditions and injury severity is not detectable. In about 70% of the cases in urban areas and in about 45% of the cases in non-urban areas involving injuries to persons the passenger car is the other vehicle concerned. In rural areas the single vehicle accident is of special interest. In 46% of such accidents physical injury results. Because in Germany there are no public data available which deal with road alignment, individual PTW accident scenarios could singly be defined in a very restricted way.

The Netherlands

The VOR (Traffic Accident Registration) database is a national Dutch database of the Adviesdienst Verkeer en Vervoer (AVV). The AVV is part of the Dutch Ministry of Transport, Public Works and Water Management. The data in the database comes from police records. The nature of the report about an accident depends upon the severity of the accident: the more severe an accident is the better is the extent ad quality of the report. Regarding the injury level classification a fatality is coded when a person dies at the accident spot or if a person is hospitalised and dies within 30 days after the accident; a seriously injured person is coded if hospitalised.

The Dutch statistics for 2002 show a total of 8,676,393 licensed vehicles including 968,922 PTWs (11.2%). Mofa and Mopeds are roughly 4 times more common than motorcycles. In only 4% of all accidents a powered two-wheeler was involved but these were accountable for more than 17% of all fatalities and almost 26% of all seriously injured persons in the year 2002. During the last few years the overall trend in The Netherlands for PTW accidents has been downwards. The main age group of moped riders is the 16-18 year olds and for motorcycle riders the 25-35 year olds. This is true for both urban and non-urban areas and again the predominant gender of PTW users is male. Regarding accident location, most mofa/moped casualties happen inside urban areas on dry roads whereas no clear distinction is possible for motorcyclists. Although for motorcycles the proportion of urban and rural accidents is nearly the same, as would be expected the more serious accidents tend to happen outside urban areas. As far as the time of day of the accident is concerned, the rush hour in the evening between 3 p.m. and 8 p.m. is when most accidents occur. Even though road usage intensity statistics show a double peak with an additional one in the morning rush hour, inexplicably a concentration of PTW accidents at that time cannot be observed. Most of the accidents occur in the months where there are many PTWs on the road, in both early and late summer. During summer holidays in July the overall road use is less. The majority of PTW accidents occur on rural straight roads and at urban intersections with a car as the other vehicle involved, while motorcycles are associated with a significant share of severe single accidents taking place on curves outside urban areas. In more than 25% of all run-off the road accidents with PTWs involved a tree or a pole is hit.

Spain

The Spanish road accident database is managed by the DGT (General Directorate of Transport), a public organisation subordinate to the Ministry of Interior. The Spanish road accident database contains the whole population of accidents in Spain in which, at least, one person has been injured as consequence of the accident. Information contained in Spanish DGT database is collected by the police forces. In a reported accident between two vehicles the design of the database forms fails to distinguish which vehicle is the target and which one is the bullet. The variable “accident type” refers only to the global configuration of the accident, but there is no information regarding the kind of impact received by each vehicle. Regarding the injuries, the DGT database contains four categories of injured people: fatal, serious, slight and uninjured. Police agents judge the severity of the injuries and assign one of these values to each casualty. Furthermore, subsequent information about casualties is given within 24 hours and not within 30 days. To compensate for this deviation from the European standard, calculated correction factors are provided by the DGT.

In Spain 3,561,450 powered two-wheelers were registered in 2002. This amounts to 13% of all licensed vehicles in the country. A PTW was involved in more than 32% of all accidents with almost 22% of all accidents involving mofas/mopeds. In traffic accidents PTWs accounted for more than 14% of the fatally injured and nearly 23% of the severely injured persons in 2002, even though in recent years a decreasing trend for mofas/mopeds and an increasing trend for motorcycles is observable. Considering age groups, most of the fatalities and severely injured people are below 35 years old. In respect of mofa/moped users, casualties are younger than for motorcycle users as anyone can ride a mofa/moped once they are 14 years old. In Spain, too, the majority of PTW casualties is of male gender. Within urban areas the number of accidents is higher than outside urban areas. This is true for both categories of powered two-wheelers. These accidents usually occur on dry and clean roads in daylight in the summer period. As far as accident scenarios are concerned, large numbers of severe and fatal PTW accidents happen within urban areas at intersections and involve a car. Also run-off-the-road accidents with or without hitting a hazardous object are significant. Outside urban areas accidents at intersections, on straight roads or within a curve are highlighted.

Accident scenario selection

Following a study of the national statistics of the four different countries similar trends regarding powered two-wheeler accidents could be recognized. Although some minor differences (legislation issues, different vehicle classification etc.) have also been identified, their influence when selecting the main accident scenarios is of minor importance. When determining the most frequent and dangerous scenarios it is necessary to differentiate between those taking place in urban areas and those in non urban areas – see Table 1. Additionally, mofas/mopeds and motorcycles have been recorded separately. Consequently seven scenarios were identified as being the most significant.

Urban Area	Non Urban Area
Moped against car at intersections	Motorcycle against car at intersections
Moped against car on straight roads	Motorcycle against car on straight roads
Motorcycle against car at intersections	Motorcycle single vehicle accidents
Motorcycle against car on straight roads	

Table 1: Selected PTW accident scenarios

Taking the four analysed countries as a whole these accident scenarios can be listed in order of importance in terms of the total number of accidents which occurred:

- Urban – Moped – Car – Intersection.
- Urban – Moped – Car – Straight road.
- Urban – Motorcycle – Car – Intersection.
- Urban – Motorcycle – Car – Straight road.
- Non-urban – Motorcycle – Single vehicle accident.
- Non-urban – Motorcycle – Car – Straight road.
- Non-urban – Motorcycle – Car – Intersection.

The results derived from the national statistics analyses were intended to be further examined by means of in-depth database analyses. Rider and vehicle kinematics, accident causes and sustained injury patterns have been elaborated as well as detailed impact configurations.

In-Depth Database Analysis

Within the SP 4 consortium several in-depth databases were available to explore. From Germany the DEKRA database, the GIDAS 2002 database and the COST 327 database, from the Netherlands the Dutch part of the MAIDS database. The following database descriptions were extracted literally from the public project report and give a brief insight into the database origins, particularities and data restrictions [3]. As expected, not all the requested information was obtainable from the four databases so that the composite results are the best available in those circumstances.

DEKRA database

The fundamental basis of the DEKRA accident database is the accumulation of written expert opinions containing the accident analyses that are drawn up by skilled forensic experts at the DEKRA branches throughout Germany and totalling about 25,000 annually. The particular feature of these reports is that normally the experts are called by the police or prosecuting attorney to come to the accident scene directly after the accident happened. They have to answer case specific questions in their expert opinions. Therefore they have the right to determine the accident circumstances, which includes, if necessary, a detailed technical inspection of the involved vehicles. The DEKRA experts operate all over Germany on a 24 hour/7 day week basis. Consequently, the nearly 500 DEKRA accident experts have the opportunity to acquire all the information necessary for their task. The reports provide a substantial basis for accident research work. The DEKRA Accident Research and Crash Test Center has the opportunity to select and analyse interesting cases which normally consist of the written expert opinions, detailed accident reconstructions, sketches and photo material. Sometimes single injuries are described but by and large only the general injury severity is stated. The actual DEKRA PTW database comprises 350 cases from 1996 to 2005 with all kinds of other vehicles as well as single PTW accidents. About 300 parameters per accident are reviewed when using the DEKRA questionnaires. Since expert opinions are normally commissioned only when the accident is of a really serious nature, the main focus of the PTW database is directed towards accidents resulting in severely or fatally injured persons. These accidents happen mostly in rural areas and involve high speeds. Therefore, the outcome of each accident and the relevant impact velocities have to be interpreted under the circumstances mentioned above.

GIDAS database

GIDAS stands for "German In-Depth Accident Study" which is being carried out by two independent teams. The Hannover team is sponsored by BASt (Federal Highway Research Institute) while an industry consortium under the auspices of VDA/FAT is financing a second investigation team at the Technical University of Dresden. Both teams share a common data structure and the cases are stored in a single database. A random sampling scheme was introduced in August 1984 and is still in use. So 1985 is the first year for which this database can be considered representative of the German national statistics. Accidents are investigated at scene using blue-light response vehicles. In most cases extensive photo documentation is also available. The data cover the accident situation, participants (including cars, motorcycles, pedestrians/cyclists, trucks, buses, trams, trains), accident cause, injury cause, human factors and vehicle technologies. The qualifying criteria are that

- the road accident resulted in at least one person being injured,
- the accident occurred within specified regions around Hannover or Dresden,
- the accident occurred while the team was on duty (2 six-hour shifts per day, alternating on a weekly basis).

Approximately 2,000 new accident cases are investigated each year. The GIDAS 2002 dataset which was analysed for the several tasks within the exercise was purchased from DEKRA and relates to 230 powered two-wheelers and 248 PTW users.

COST 327 Database

The organisation European Co-operation in the Field of Scientific and Technical Research (COST) 327 was formed to investigate head and neck injuries suffered by motorcyclists by carrying out a comprehensive and detailed analysis. The COST 327 accident database consists of 253 cases collected from July 1996 to June 1998 in the UK by the Southern General Hospital, Glasgow, in Germany by the Medical School of Hannover and Munich University (LMU) and in Finland by the Road Accident Investigation Team. All cases are characterised by the following criteria:

- a powered two-wheeler was involved,
- a full or open face helmet was worn,
- head/neck injuries of AIS 1 or above were suffered – or known head/helmet contact without head injuries occurred.

Head injuries occurred in 67% of all cases. In 27%, a neck injury was sustained. The proportion of head injuries was considerably higher with MAIS 3 and above (81%) than with MAIS 1 (38%). The effect of climatic conditions on accident risk was investigated but found difficult to determine, however, due to the retrospective character of the study.

NL–MAIDS database

In order to better understand the nature and causes of PTW accidents, the Association of European Motorcycle Manufacturers (ACEM) with the support of the European Commission and other partners conducted an extensive in-depth study of motorcycle and moped accidents during the period 1999-2000. Sampling was carried out in five areas located in France, Germany, Netherlands, Spain and Italy, resulting in a large PTW accident database called after the MAIDS (Motorcycle Accident In-Depth Study) project. The methodology developed by the Organisation for Economic Co-operation and Development (OECD) for on-scene in-depth motorcycle accident investigations was used by all five research groups in order to maintain consistency in the data collected in each sampling area. A total of 921 accidents was investigated in detail, resulting in approximately 2,000 variables being coded for each accident. The investigation included

- a full reconstruction of the accident,
- detailed inspection of vehicles,
- interviews with accident witnesses,
- collection of factual medical records relating to the injured riders and passengers. These were subject to the applicable privacy laws and were obtained with the full cooperation and consent of both the injured person and the local authorities.

The in-depth data gathered in the Netherlands by TNO are part of the MAIDS database. In this part of the database 200 accidents were investigated and coded. The accidents incorporated were all PTW accidents in the Haaglanden region (The Hague, Rotterdam), in which a police alert was sent to the Dutch accident research team. The coverage was over 90% of all PTW accidents in the region. The accidents were accordingly put into two databases:

1. Database relating to the accident configuration, vehicle and rider/passenger information.
2. Database relating to injuries. Each injury is a separate data field and is assigned to a particular accident by means of the accident identification code. Only the rider injuries were considered in the investigation, because passenger injuries had not been included yet in the injury database.

PTW–Car accidents

Data from the national accident statistics of Germany from the years 1994 to 1999 were analysed in a study by ASSING in 2002 [4] in which the principal causes leading to PTW accidents were explored. In 11% of the cases the PTW user was responsible as a result of wrong road use, in 25% by failing to respect priority or to give way and in 42% by left or right turn manoeuvres. In the cases where a car was involved 34% of the incidents were caused by a priority/give-way violation. In 2004, HUANG & PRESTON stated that in many multi-vehicle crashes involving motorcyclists, the motorcycle was either not seen or seen too late by the other involved vehicles [5]. This has to do with the size of a motorcycle, which is rather small, and the fact that they are less frequently encountered in traffic situations. On the whole other drivers are not so accustomed to their presence on the roads as they are to cars. Other than that, car drivers who ride a motorcycle themselves or who relate in some way to motorcycle riders are less likely to collide with motorcyclists. In multiple vehicle crashes the other vehicle fails to give way in two thirds of the cases. The main scenario involves a motorcycle going straight ahead and a car turning left into a side road. In single vehicle crashes a pre-accident error contributed to the actual accident. ABS will improve the active safety of the motorcycle rider. Secondary safety devices like airbags and leg protectors will improve rider safety in most cases, but may have some negative side effects. A comprehensive PTW accident study on Dutch roads was published by KAMPEN & SCHOON in 2002 [6]. Regarding the direction of impact, in more than 60% of the cases the front side of the PTW was hit. Side impacts to the second vehicle occurred in approximately 35% of the motorcycle cases and 30% of the moped cases. In 1991 KAUTZ analysed 501 motorised two-wheeler accidents in the Dresden area in Germany. He found that in 41% of the cases the PTW user was responsible for the accident, 22% were single vehicle accidents and the opponent most frequently hit was a car [7]. In the accidents caused by motorcyclists, in 23% speeding was a contributing factor and in half of all accidents a failure to see the PTW by the driver of the car led to the accident. In the accidents where faults in driving manoeuvres were made, 44% of the riders had less than 2 years riding experience. Fatal motorcycle accidents in England and Wales have been analysed by LYNAM in 2001 [8]. Within those 717 accidents about 60% involved cars but where the motorcyclist was claimed to have caused the accident. In 44% the main contributing factor was speeding. Single vehicle accidents were mostly due to loss of control and travel speeds well above 40mph in rural areas. OSENDORFER & RAUSCHER mentioned in their

BMW C1 study that 42% of the analysed PTW accidents were frontal collisions and in half of the cases a car was the other vehicle involved [9]. In 1985 SIMARD examined more than 24,000 motorcycle accidents in the Quebec region in Canada and concluded that failure to give way was a major cause of severe motorcycle-car side impacts [10]. Furthermore, another typical accident cause involved a car driving well over on the right-hand side and then turning left while the motorcycle was overtaking. As far as collision types are concerned, SPORNER stated in his study from 1995 taking 528 motorcycle-car accidents into account, that the majority of the collisions could be categorised into 14 main collision types. The principle characteristic of these was that the front of the PTW (60% of the cases) hit the front of the passenger car. A front corner of the passenger car was hit in 45% of the cases. When considering the angle between the longitudinal axes of the vehicles, more than 50% of the cases were the result of an almost perpendicular side impact (23%) or of an opposing angled (frontal-oblique) impact (32%) [11]. In a recent study from BERG regarding national German data for 2002 a brief analysis on accident types is given. It is mentioned that 70% of the motorcycle crashes in urban areas (n=20,979) involved a passenger car as the second party. On rural roads (n=12,952) this was 46% [12]. A survey from OTTE in 1998 quoted that in 64% of the analysed events in German and UK national statistical data a car was the second involved party in PTW accidents [13].

In the in-depth databases the two-vehicle categories mofa/moped and motorcycle should have been analysed separately. After an initial inspection regarding the selected accident scenario distribution in the four databases (Table 2), it was decided to analyse all powered two-wheelers together because separation would have led to very small case numbers which had no statistical significance. The Dutch part of the MAIDS database is provided by TNO, the COST 327 database by LMU (Ludwig-Maximilians- University) and the appropriate abbreviations are used in Table 2.

Large differences are to be observed within the different databases. This is primarily related to the different data acquisition methods and their inclusion criteria. The only relatively high coincidence occurs in the case of urban areas with motorcycles impacting cars at intersections. In order to answer the question whether or not the PTW had the opportunity to brake before impact, the cruising speeds and the impact speeds are of interest in the case of a primary impact with the car. The possibility that the accident could have been avoided could be deduced from that information. The cruising and impact velocities were grouped into 25km/h bands and the cruising speed was cross-correlated to impact speed, Figure 2 to Figure 4. It can be seen that the impact speed is nearly always in the same band as the cruising speed. This does not mean that there was hardly any

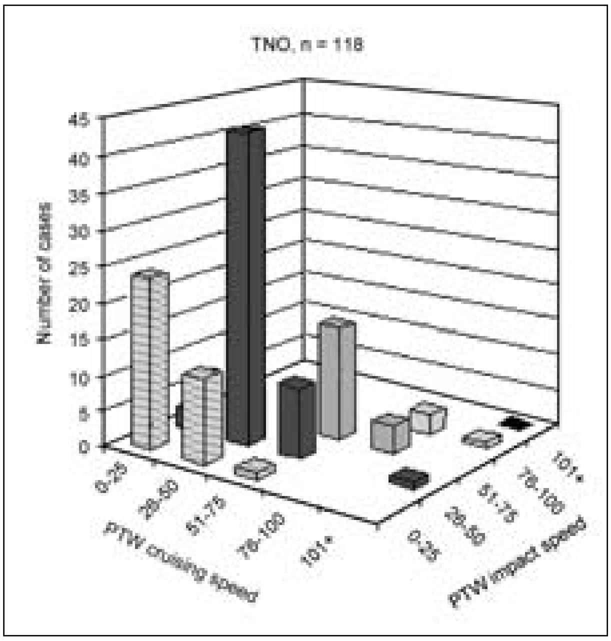


Figure 2: PTW cruising speed and impact speed, TNO MAIDS

	TNO n=85	DEKRA n=157	GIDAS n=128	LMU n=76
Urban – Moped – Car – Intersection	49%	5%	12%	4%
Urban – Moped – Car – Straight road	12%	1%	3%	1%
Urban – Motorcycle – Car – Intersection	21%	29%	55%	42%
Urban – Motorcycle – Car – Straight road	11%	11%	21%	22%
Rural – Motorcycle – Car – Intersection	4%	38%	3%	13%
Rural – Motorcycle – Car – Straight road	4%	16%	6%	17%

Table 2: Accident scenario distribution within the four databases

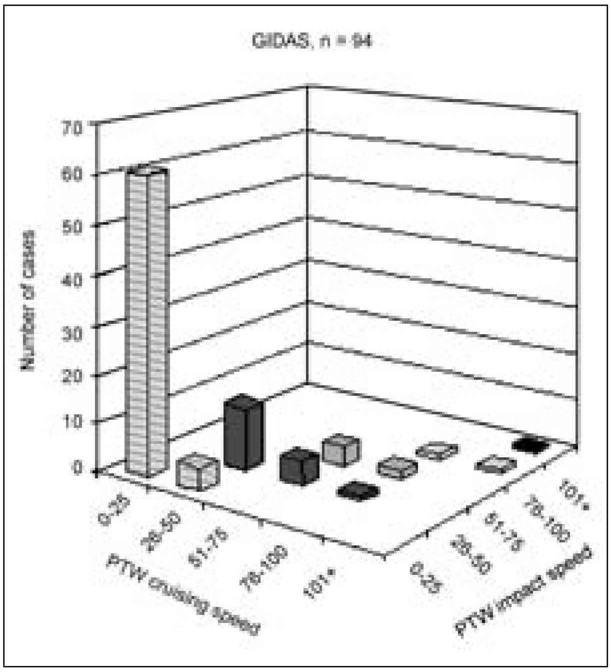


Figure 3: PTW cruising speed and impact speed, GIDAS 2002 data

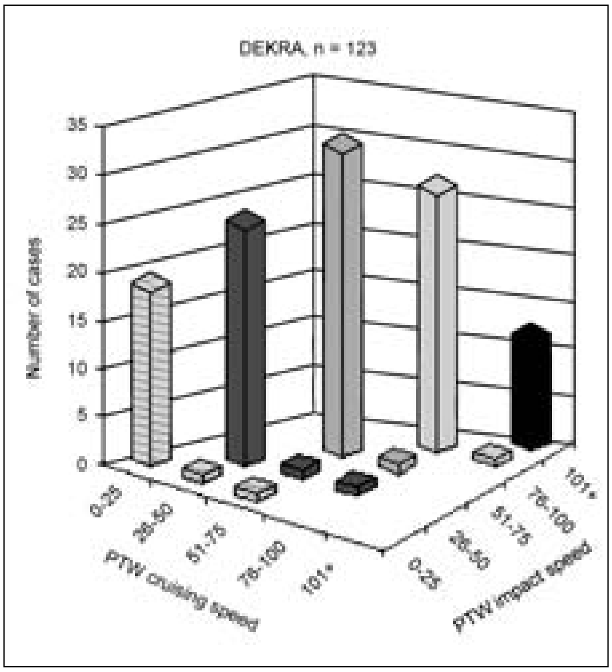


Figure 4: PTW cruising speed and impact speed, DEKRA data

speed reduction, but it does indicate that the speed reductions were not extremely high. The conspicuous high cruising and impact speeds in the DEKRA database are related to the fact that most of the severe and fatal accidents which are recorded are associated with the higher speed bands. It is possible to derive from each of the databases any accident avoidance manoeuvres that were attempted such as swerving, branking using both front and rear brakes or combined braking and swerving. Nevertheless in up to 94% of the analysed cases these actions were unsuccessful. This could often be a matter of timing, like such as braking too late or a matter of insufficient brake power due to wet roads or skidding.

PTW-to-car impacts with the PTW moving upright prior to the impact could be coded in the ISO 13232 format. This three digit code enabled a classification to be made of the contact points of the vehicles and their respective heading angle at the moment of first impact [14]. In most of the impacts the PTW was still upright and the rider was not separated from the PTW at the time of impact. This was true in typically 55% of the cases. ISO constellations could be directly gathered from the DEKRA database in which they are coded. For the TNO MAIDS database it was possible to assemble the data from the relative heading angle of PTW and car and the impact locations on PTW and car. The variety of impact constellations is substantial and they do not show a clear trend. However front-front and front-side PTW to car impacts are the most relevant ones, Figure 5. The next item to be considered is the type and severity of injuries suffered by the PTW user. In the databases from LMU and GIDAS, the lower extremities are hit most often, followed by the head, then the upper extremities and thorax. It should be noted that LMU data have the head-neck injury inclusion criterion so that the amount of injuries to that body region will be over-represented. Furthermore the lower extremities portion in the GIDAS data is very large. The object hit is primarily the car, followed by the road and the PTW. For the head and the neck there are few cases recorded where another object was hit. This could have been for instance a road-side structure, Figure 6 and Figure 7.

The injury severities reported from the GIDAS 2002 database are shown in Figure 8. The thoracic injuries are commonly not very severe when compared with the other databases. This is an unexpected result but it should be kept in mind that the head injuries in GIDAS are also relatively slight, whereas in the COST 327 database such injuries are extremely severe. This is related to the fact that the GIDAS database is representative according to the German National Statistics. Here, more than 68% of the PTW accidents occur in urban areas where the driving speeds are relatively low. The proportion of slightly injured PTW users (67%) is also representative in regard of the National Statistics.

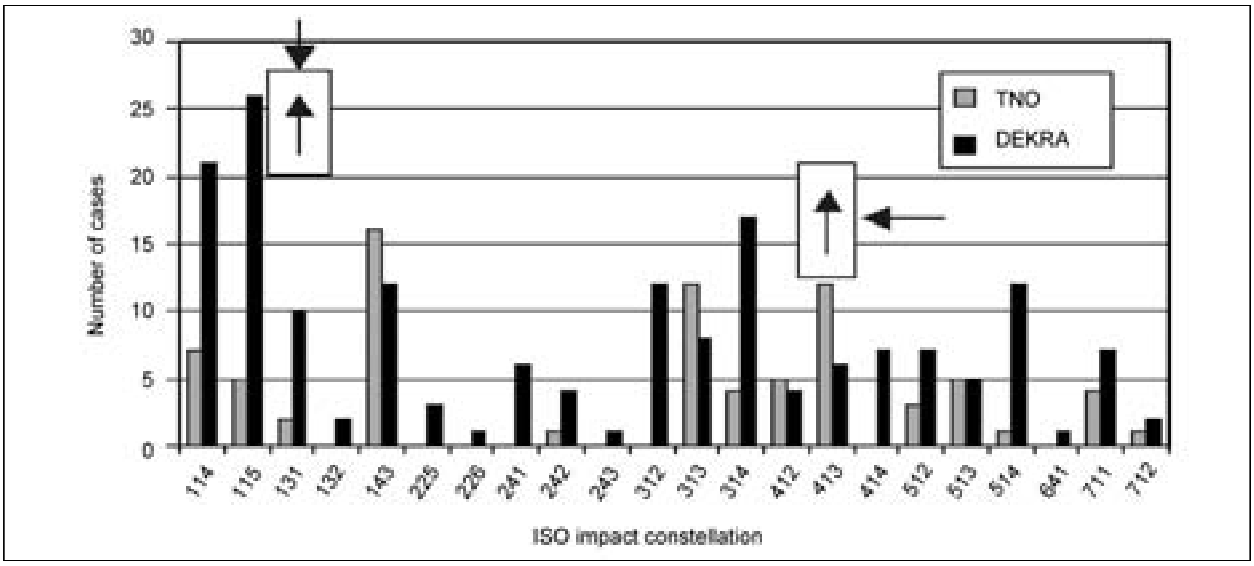


Figure 5: ISO impact constellations, TNO- MAIDS and DEKRA databases

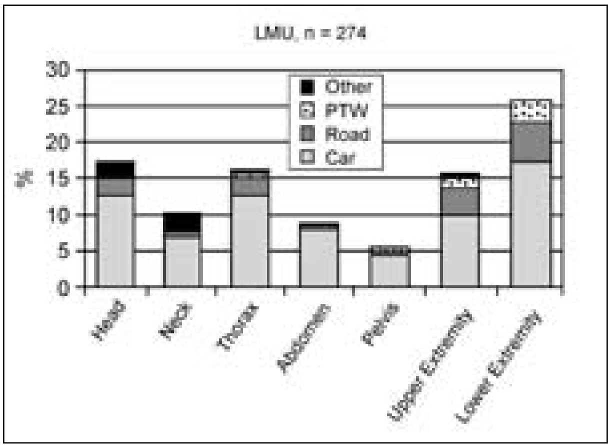


Figure 6: Primary body region affected by the impact, LMU COST 327 data

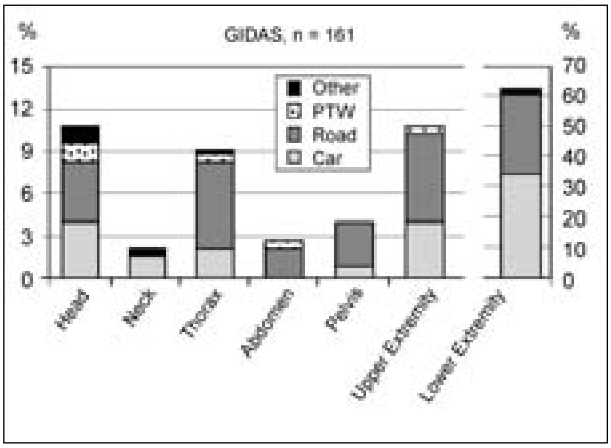


Figure 7: Primary body region affected by the impact, GIDAS 2002 data

The location where the rider finally ends up after the impact is called the rider point of rest (POR). This position is often very different from the point of impact (POI) and the distance between them can sometimes be quite large [15]. The ways in which this distance between POI and POR is covered can be very diverse and are coded differently in the databases used. The TNO data show a large number of throws, almost equal to the combined number of tumble/roll/skid types of transition, while the German LMU and DEKRA data contain a very large number of these tumble/roll/skid types of transition. Additionally the relation between POI and POR in regard to injury severity was analysed. It could be observed that contact with the car caused more severe injuries to head, abdomen and thorax, while the accidents with a large POI-to-POR distance have relatively more low-severity upper- and lower extremity injuries. When comparing

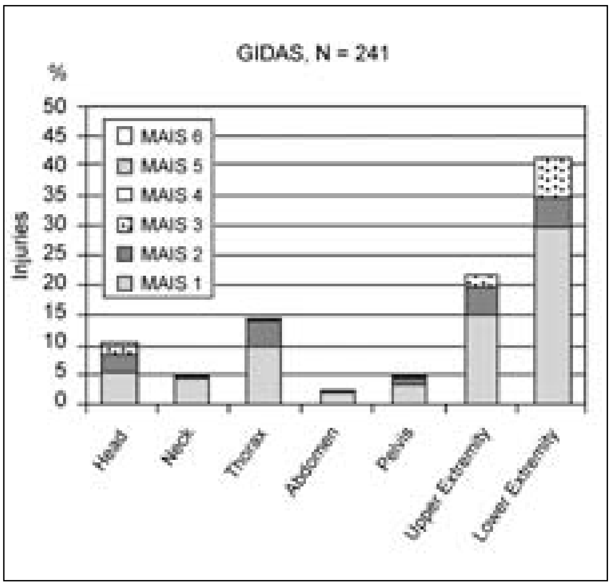


Figure 8: MAIS injury level with respect to specific body areas, GIDAS 2002 data

accidents with long POI-to-POR distances (>10m) with accidents with short POI-to-POR distances (<10m) it can be seen that in the short POI-to-POR distance accidents

- the injury is frequently caused by contact with the car;
- the injuries are more severe on average;
- head and abdominal injuries occur more often and are more severe;
- thorax injuries are more severe;
- upper and lower extremity injuries are less often encountered.

Concluding, the main cause of PTW accidents is related to perception failure. If the PTW user tries to avoid the accident, front and rear brakes are often applied, however, mostly without success. As a consequence the PTW hits the car, or the car hits the PTW with the rider seated in an upright position. The rider either hits the car first, resulting in severe head or abdominal injuries or ejects from the PTW, resulting in a vault or throw, the nature of which is dependent on the impact speed and impact constellation. As a consequence the road is hit in a secondary impact and the injuries relate mainly to the extremities, these being less severe than the injuries resulting from body impacts with the car.

PTW–infrastructure accidents

As already mentioned, the GIDAS 2002 data represent the whole accident situation in Germany. For that reason, most of the registered accidents occurred inside urban areas with relatively low impact speeds and – as a result of that – relatively low injury levels. Regarding the in-depth analysis of PTW-to-infrastructure accidents, very few cases are usually available. The GIDAS 2002 data comprise only 6 barrier and 3 tree or pole impacts. Therefore this section of the paper which focuses mainly on GIDAS database analysis only summarises briefly the main results of the overall exercise [16].

The most significant obstacles involved in accidents with a particularly severe outcome were trees/poles, roadside barriers and road infrastructure elements in general also including pavement. Analysis of the collision sequences indicates that most of the obstacle impacts took place as primary impacts. Accidents involving tree/pole impact seemed to be largely single-vehicle accidents [17]. Impact speeds in accidents involving roadside barriers as an obstacle tend to be very high, whereas impact speeds did not differ outstandingly from the whole group of accidents with a tree/pole involvement as a result of being in the median range of 30–40km/h for TNO and GIDAS and 50–60km/h for Cost 327 and DEKRA data. The angle at which a rider typically left the road seemed to be very shallow and the rider thereby seemed to be aligned nearly parallel to the road. In most impacts with trees/poles and barriers the rider was upright on his PTW. When a metal guar drail was struck, the rail seemed to be hit more often than the post. A small percentage of accidents involved road-infrastructure features. Causation issues can rarely be determined for different obstacles. The impression is gained that roadside barriers cause particularly severe injuries when hit. Taking into account the observed impact speeds, tree/pole impacts have to be considered to be at least as equally dangerous as barrier impacts. Obstacle impacts result in head injuries particularly often and when barrier impacts occur the lower extremities are injured nearly as often as the head.

PTW user protective devices

In order to obtain comparable data from the four different databases, a series of common charts was set up. The objectives of the analysis of these accident data records were the identification of the most frequently injured body region, the most severely injured body region, the typical injuries sustained by each body region and the verification of information about the performance of the motorcyclists' protective clothing. To reach a reliable conclusion from this analysis, it was decided to include all the accident scenarios in order to consider as many cases as possible. In a first step, a paired comparison between injured and uninjured motorcyclists was conducted. In this way the possible influence of the protective clothing worn could be derived. Additionally, the different kinds of injuries to each specific body region were analysed separately, enabling valuable conclusions to be drawn about how the protective elements should work to be most effective in the prevention of injuries. Three different impact speed ranges (0-35km/h, 36-70km/h and >70km/h) have been analysed with respect to different protective clothing combinations. This led to a primary overview of the miscellaneous protection levels in the four databases. The definition of protection level is given in Table 3. As expected, the helmet was the most frequently used item of protective clothing and therefore protection level 1 was the level achieved most often, namely by an average of 66% of the PTW users. The second most frequently achieved protection level according to the databases was level 3 by a mean of 18% of the PTW users. As far as trousers, jackets and boots are concerned it was considered that only clothing made out of leather or special heavy garment material like Kevlar or imitation leather was able to offer any protection.

By relating the previously mentioned protection levels found in the four different in-depth databases to the severity of injuries suffered by the respective riders and passengers, it could be stated that in general injury severity decreases with increasing level of protection, see Table 4. However, this is not true for level 0 where only 27 cases were available.

For the three different speed bands the rider and passenger related injuries have been further investigated and classified by means of the Abbreviated Injury Scale (AIS) coding. At speeds up to 35km/h, it was noted that only the head sustained severe injuries (AIS 3+) according to the NL-MAIDS and GIDAS 2002 data. From the COST 327 information, it was clear that the thorax and abdomen also sustained severe, critical or maximum injuries. Additionally, with an increase of impact speed, other body regions were severely injured. Particularly the spine and neck injuries were already at a critical level for the speed band of 36-70km/h. The pelvis as well as the upper extremities sustained severe injuries when the impact speed exceeded 35km/h. For the impact speed band of 36-70km/h, the corresponding impact points struck by the riders and passengers as recorded in the NL-MAIDS and the GIDAS 2002 database are shown in Figure 9. In most body regions, impact with the ground or road as well as impact against an unspecified object were considered to be responsible for the injuries. Regarding pelvic injuries it is worth mentioning that often the PTW itself (e.g. the fuel tank, handlebar, etc.) was the object responsible for causing injury.

The body regions suffering injury have been analysed separately. For the head, helmeted and un-helmeted riders and passengers have been compared in order to identify possible protection effects. Different helmet types such as full-face helmet, jet helmet and half-shell helmet have been analysed within the three impact speed bands. The data showed that a significant number of riders did not use a helmet. This is due to the fact that in the Netherlands a helmet is not compulsory for low-speed mopeds. Compared to the un-helmeted PTW users those wearing a helmet suffered lower injury severity levels. This is true for all impact velocities. For impact speed values up to 35km/h, the helmet was effective in preventing severe injuries while, as soon as the impact speed values increased, the number and the severity of different types of injuries increased too. Additionally the helmet situation was split into 18 sectors and the damage to each of

Protection Level	Clothing combination	Protection Level	Clothing combination
0	No protection	1	Helmet
	Jacket		Helmet and boots
	Trousers		Helmet and gloves
	Jacket and trousers		Helmet and trousers
	Jacket, trousers and boots		
2	Helmet, gloves and boots	3	All the body covered
	Helmet, jacket and boots		Helmet, jacket and trousers
	Helmet, jacket and gloves		Helmet, jacket, trousers and boots
	Helmet, jacket, gloves and boots		Helmet, jacket, trousers and gloves

Table 3: Protection levels and respective clothing combinations

Protection level	Number of cases	Not injured	Slightly injured	Severely injured	Killed
0	27	3.7%	55.6%	33.3%	7.4%
1	586	1.9%	19.6%	39.8%	33.3%
2	102	0.0%	31.4%	36.3%	32.4%
3	159	1.9%	37.1%	32.1%	28.9%

Table 4: Injury distribution in relation to protection level

those as well as the corresponding injuries were analysed. It was found out that the critical regions were the forehead and the rear part of the helmet. Loss of the helmet during the impact was found not to be an unusual event. Improvements to the strap and/or the fitting of the helmet to the head were classified as effective countermeasures.

For facial injuries only NL-MAIDS and GIDAS 2002 data were taken into account because in the COST 327 database these injuries are included in the head section. Here, too, the different helmet types and the impact speed ranges have been considered. Again, it was found that the helmet is capable of preventing injuries, although it was

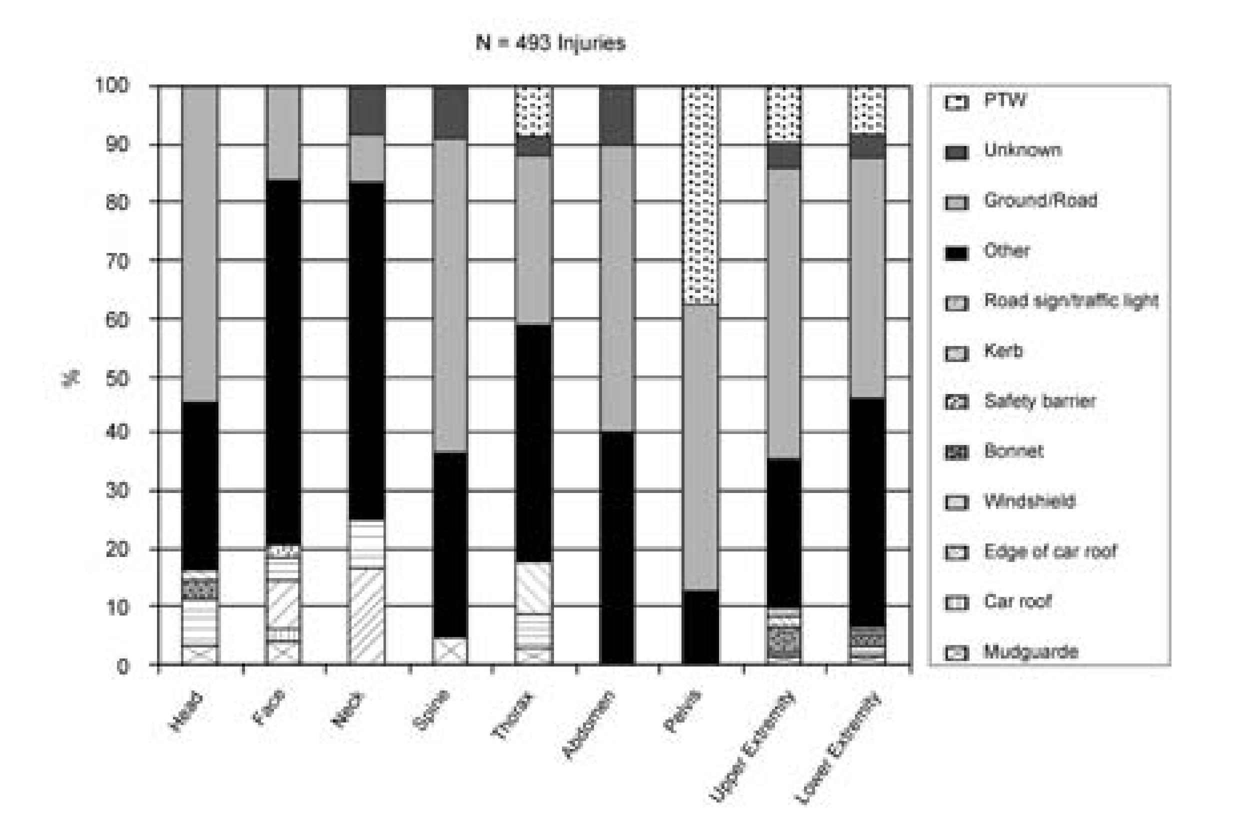


Figure 9: Spread of injuries and related impact locations for the impact speed band 36-70km/h, according to NL-MAIDS and GIDAS 2002 data

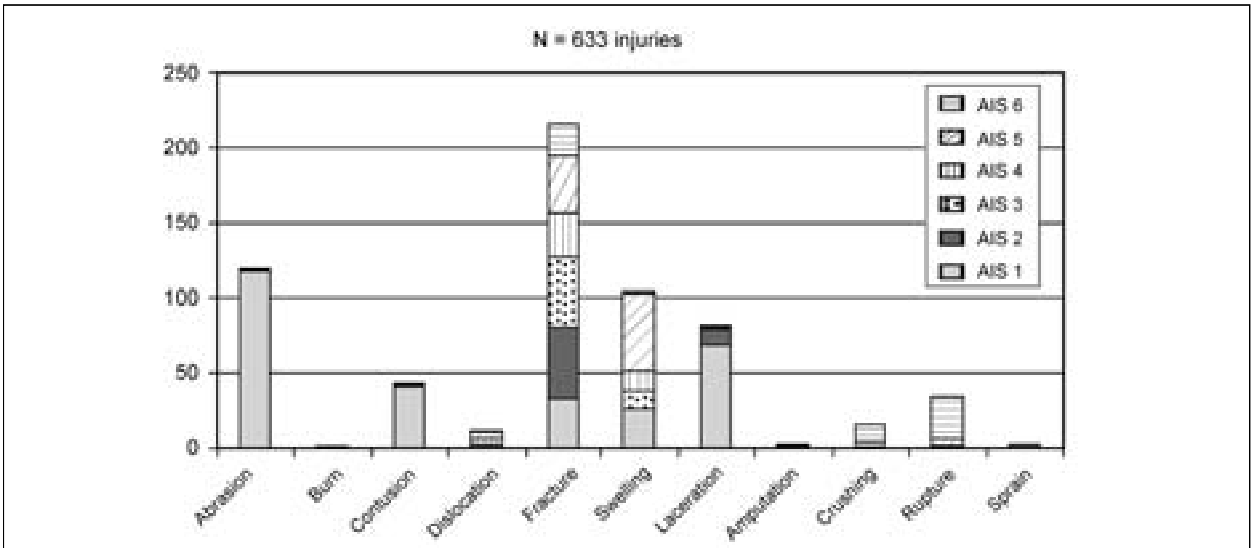


Figure 10: Injury types and severity levels for the neck, COST 327 database

noted that regardless of the impact speed the recorded AIS levels for the face were very low. They consisted mostly of abrasions, contusions and lacerations.

As far as the neck is concerned in NL-MAIDS and GIDAS 2002 databases, only the soft tissue injuries have been taken into account. The more severe skeletal injuries have been analysed separately in the spine section. Because of this, neck injury severity levels recorded in NL-MAIDS and GIDAS 2002 are lower than those found in COST 327 cases. The likelihood of soft tissue injuries in the neck is very low. In the case of COST 327 data where skeletal injuries were also included, the frequency and severity of neck injuries increased significantly for impact speeds higher than 35km/h. The different kind of injuries to the neck found in the COST 327 database are shown in Figure 10. Mostly AIS 1 injuries were recorded which normally refer to soft tissue injuries such as abrasions, lacerations or contusions. The severe neck injury types (AIS 3+) consisted of dislocations, fractures, swelling, crushing, and rupture.

Protected – meaning the wearing of leather clothes or heavy garments – and unprotected PTW casualties have been compared for their influence upon injury to the upper extremities. From the GIDAS 2002 and NL-MAIDS data, it can be seen that the frequency with which injuries to the upper extremities were sustained was reduced when protective clothing was worn, regardless of the impact speed. From the analysis of COST 327 data a similar situation is obtained, except for the impact speed band of 36km/h to 70km/h. No matter what impact speed or what database was taken into account, it can be stated that wearing protective clothing seemed to reduce the level of injuries. In fact, comparing casualties to injuries, 74 injuries were recorded for 51 harmed protected riders whereas 152 injuries emerged for 89 unprotected riders. The same analysis has been performed for the COST 327 data which respectively showed a total amount of 66 injuries for 46 injured protected riders against 169 injuries for 109 unprotected hurt riders. As far as the distribution of injury severity is concerned, it can be stated that the use of motorcyclist protective clothing had some benefits particularly at impact speeds up to 35km/h. The most common injury types were abrasions, fractures and contusions.

Almost the same conclusions could be drawn for the lower extremities as for the upper extremities. Wearing rider protective clothing significantly reduced the amount and the severity of injuries sustained at all impact speeds. For 49 wounded protected riders 85 injuries were recorded whereas for the unprotected riders 160 casualties with 331 injuries arose (NL-MAIDS and GIDAS 2002). The same trend was illustrated by the COST 327 data which showed a total of 59 injuries for 43 injured protected riders while 297 injuries were recorded for 161 unprotected harmed riders. The most frequent types of injuries were contusions, abrasions and fractures.

Analyses dealing with spinal injuries demonstrated that motorcyclist protective clothing is helpful in reducing the injury severity and the number of injuries in comparison to the number of casualties in all speed bands. Although there are not many cases available from GIDAS 2002 and Dutch MAIDS data, this trend could also be observed here – 18 injuries were recorded for 17 injured protected PTW users whereas 19 injuries were sustained by 14 harmed PTW users. The most frequent of the spinal injuries were fractures and distortions in the cervical spine area.

The data concerning thorax injuries confirmed that contusions and fractures in that order were the most frequent injuries. With regard to injury severity, damage to internal organs was the most critical aspect. From COST 327 data also, fracture was found to be one of the most severe types of injury but in this case, the data also included spinal injury and this affirmed the outcome of the previous section relating to the spine.

Summary and Future Steps Action

In order to reach the ambitious target to cut in half the number of road users killed every year by 2010 (based on the 2001 figures) for the EC-15 countries, special attention must also be paid to PTW accidents. Consequently, a sub-project dealing with motorcycle accidents was established within the APROSYS IP of the 6th Framework Programme of the EC. A two-step investigation of the PTW accident records has been completed. The National Statistics of four European countries for the years 2000–2002 have been analysed and found to show similar trends for the specific matters of concern which were examined. Seven main PTW accident scenarios were identified which have been further investigated via in-depth databases. The analyses of these scenarios have been conducted by making use of the DEKRA PTW database, the GIDAS 2002 database, the COST 327 database and the Dutch element of the MAIDS database:

Urban – Moped – Car – Intersection.

Urban – Moped – Car – Straight road.

Urban – Motorcycle – Car – Intersection.

Urban – Motorcycle – Car – Straight road.

Non-urban – Motorcycle – Single vehicle accident.

Non-urban – Motorcycle – Car – Straight road.

Non-urban – Motorcycle – Car – Intersection.

In a subsequent step, three different tasks have been set up dealing with PTW-to-car accidents, PTW collisions with infrastructure features and the performance of rider protective devices. For the PTW–car accidents it was found that the outcomes of former studies in the field could be endorsed. Most PTW-to-car accidents resulted from a perception failure. As far as the ISO 13232 impact constellations are concerned, it was possible to confirm front-front and front-side impacts of the PTW with the car as being the most frequent. Accident avoidance manoeuvres on the part of the PTW were sometimes accomplished through braking and/or swerving but with little success. On average, injuries suffered by the PTW users were more severe when caused by contact with the car. In the case of PTW collisions with infrastructure features the most significant obstacles involved in accidents with a particularly severe outcome were trees/poles, roadside barriers and road infrastructure features in general including pavement. Frequently the collision with a road infrastructure feature constituted the primary impact. Roadside barriers appeared to cause particularly severe injuries when struck, a noteworthy point here being that the impact angles were rather shallow. Obstacle impacts led to head injuries particularly often and the lower extremities were injured nearly as often as the head. For the determination of the effectiveness of protective devices used by PTW drivers, a paired comparison between protected and unprotected casualties has been carried out in which four protection levels were defined. The analyses were focused on the impact speed bands of 0-35km/h, 36-70km/h and exceeding 70km/h. Even at velocities up to 35km/h, it was noted that the head, thorax, pelvis, abdomen and the upper extremities sustained severe, critical or maximum injuries. Analyses of spinal injuries demonstrated that motorcyclist protective clothing is helpful in reducing both the injury severity level and the number of injuries which are sustained in accidents occurring in all speed bands.

In the next stage of the project which deals mainly with PTW collisions with infrastructure features and the evaluation of rider protective devices, in-depth data as well as real crash test data will be further investigated. In particular, rider and PTW kinematics prior to, at the time of and after the collision are to be determined. Parameters such as impact angles, trajectories, POI-to-POR distance etc. will be gathered on a case-specific basis in order to define a model scenario. This model scenario will be reconstructed and visualized using multi-body simulation tools. Injuries will be simulated via human body models such as PAM Crash and RADIOSS. The output of the simulations will then be compared with the real accident data sets so as to validate the fitness of the simulations. Furthermore, a proposal for a test procedure to evaluate metal barriers will be developed as well as a concept design for motorcyclist safety in the context of roadside infrastructure features. Additionally, the problem of providing improvements to motorcyclist safety helmets and protective clothing will be addressed. Data relating to vehicle motion and impact behaviour will be studied in order to define working and activation parameters for complementary safety devices.

References

[1] FP6 APROSYS SP4: Deliverable D4 – 1 – 1, Public Report, 2005

[2] Annual statistical report: the SafetyNet Consortium, February 2005

[3] FP6 APROSYS SP4, Deliverable D4 – 1 – 2, Public Report, 2006

[4] K. ASSING (2002): Schwerpunkte des Unfallgeschehens von Motorradfahrern. Bundesanstalt für Straßenwesen, Mensch und Sicherheit, Heft M 137

[5] B. HUANG, J. PRESTON (2004): A literature review on motorcycle collisions. Final report, Oxford University

[6] L.T.B. KAMPEN, C.C. SCHOON (2002): Tweewielerongevallen (Two-wheeler accidents). SWOV report R-2002-5

[7] A. KAUTZ (1991): Statistical Analysis of motorcycle accidents in Dresden. Proceedings of the 1991 International Motorcycle Conference. Pp 107-115 (IFZ No. 7)

[8] D. LYNAM, J. BROUGHTON, R. MINTON, R.J. TUNBRIDGE (2001): An analysis of police reports of fatal accident involving motorcycles. TRL Report 492

[9] H. OSENDORFER, S. RAUSCHER (2001): The development of a new class of two-wheeler vehicles. Proceedings of the 17th ESV Conference

[10] B. SIMARD (1985): Quelques aspects des accidents de motocyclettes survenus au Québec entre 1980 et 1983. Proceedings of Canadian Multidisciplinary Road Safety Conference IV. Pp 476-488

[11] A. SPORNER, J. POLAUKE, J. van DRIESSCHE (1995): Collision Parameters from real-life car/motor cycle accidents. A basis for future standards. SAE paper 950203

[12] F.A. BERG, P. RÜCKER, J. KÖNIG (2004): Motorcycle crash tests – an overview. ICRASH 2004 Conference Paper

[13] D. OTTE, H. WILLEKE, N. CHINN, D. DOYLE, E. SCHULLER (1998): Impact mechanisms of helmet-protected heads in motorcycle accidents. Accidental study of COST 327. Proceedings of the 1998 International Motorcycle Conference. Pp 83-109 (IFZ No. 8)

[14] ISO 13232-2:1996 Motorcycles: Test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles – Part 2: Definition of impact conditions in relation to accident data

[15] A. SPORNER: Elemente eines Sicherheitsmotorrades. Motorradforum "Faszination und Sicherheit", Querschnitt durch die aktuelle Motorrad-Sicherheitsforschung. Institut für Zweiradsicherheit e. V., Köln (1988)

[16] FP6 APROSYS SP4: Deliverable D4 – 1 – 3, Public Report, 2006

[17] F.A. BERG, P. RUECKER, M. GAERTNER, J. KOENIG, R. GRZEBIETA, R. ZOU (2005): Motorcycle Impacts into Roadside Barriers – Real-World Accident Studies, Crash Tests and Simulations Carried out in Germany and Australia. Proceedings of the 19th International Technical Conference on the Enhanced Safety of Vehicles

S.N. Huang, J.K. Yang
Division of Vehicle Safety, Chalmers University of Technology, Göteborg, Sweden

F. Eklund
Automotive Safety Electronics, Autoliv Electronics AB, Linköping, Sweden

Analysis of Car-Pedestrian Impact Scenarios for the Evaluation of a Pedestrian Sensor System Based on the Accident Data from Sweden

Abstract

There is a need for detecting characteristics of pedestrian movement before car-pedestrian collisions to trigger a fully reversible pedestrian protection system. For this purpose, a pedestrian sensor system has been developed. In order to evaluate the effectiveness of the sensor system, the in-depth knowledge of car-pedestrian impact scenarios is needed.

This study aims at the evaluation of the sensor system. The accident data are selected from the STRADA database. The accident scenarios available in this database were evaluated and the knowledge of the most common scenarios was developed in terms of the pedestrian trajectory, the pedestrian speed, the car trajectory, the car velocity, etc. A mathematical model was then established to evaluate the sensor system with different detective angles. It was found that in order to detect all the pedestrians in the most common scenarios on time the sensor detective angle must be kept larger than 60 degrees.

Notation

V_p pedestrian speed

V_c car velocity

T_r latency of the sensor and protection system

D_p walking distance of the pedestrian within the latency of the sensor and protection system

Y_c Y-coordinate of the collision point

Y_p Y-coordinate of the pedestrian

D_c critical reaction distance of the sensor and protection system

α half detection angle of the sensor system

D_s detection distance of the sensor system

P probability of the pedestrian being detected on time by the sensor system

1 Introduction

In order to trigger a fully reversible pedestrian protection system on time, an active sensor system was developed by Autoliv to detect and identify the pedestrian moving characteristics before car-pedestrian collisions. In order to evaluate the effectiveness of this sensor system, an in-depth analysis of car-pedestrian impact scenarios is needed. Some correlative researches have been carried out for different purposes. SCHOFER et al. (1995) presented a simple four-category taxonomy of child pedestrian-motor vehicle accidents and tested the effectiveness of this classification by using objective data and the results of causal sequence reconstruction [1]. STUTTS et al. (1996) applied the NHTSA pedestrian crash-typing system to categorize 5000 pedestrian-motor vehicle collisions reported by the U.S. police [2].

The present study aims to evaluate the sensor effectiveness for pedestrian detection. For this purpose, two goals were achieved. The first one is to develop the qualitative and quantitative knowledge of car-pedestrian accident scenarios indicated in Table 1. The second goal is establishing a mathematical model to evaluate the sensor system.

2 Material and Method

The main data source of this study is the Swedish Traffic Accident Data Acquisition (STRADA) [3]. The car-pedestrian impact scenarios in this database were evaluated by the statistical analysis of the selected accident data and the two most common scenarios were chosen for the sensor evaluation.

Qualitative Knowledge (Description)	Pedestrian Trajectory
	Passenger Car Trajectory
Quantitative Knowledge (Distribution)	Pedestrian Speed
	Passenger Car Velocity
	Location of Collision Point on Car

Table 1: Qualitative and quantitative knowledge of car-pedestrian accident scenarios

The qualitative and quantitative knowledge indicated in Table 1 was developed for these scenarios. Using the developed knowledge, the mathematical model was established and the sensor system was then evaluated by this model.

2.1 Data collection

STRADA is a database belonging to the Swedish Road Administration (SRA). This database has been under development since 1996 and stores road accident data from police and some hospitals. From January 1st 2003, all the police stations and approximately 50% of the emergency hospitals report traffic accidents to STRADA. The accident data in this report come from the police records from January 1st, 1999 to September 13th, 2005. From the total 5673 passenger car-pedestrian impacts, 2097 impacts between a single passenger car and a single pedestrian with the identified STRADA car-pedestrian accident scenario, as shown in Figure 1 and explained in Table 2, were selected.

Scenario	Description
F1	Pedestrian crossing road; passenger car coming from the left side of pedestrian
F2	Pedestrian crossing road; passenger car coming from the right side of pedestrian
F3	Pedestrian going along the left side of road
F4	Pedestrian going along the right side of road
F5	Pedestrian crossing before intersection; passenger car going straight forward
F6	Pedestrian crossing after intersection; passenger car going straight forward
F7	Pedestrian crossing after intersection; passenger car turning left
F8	Pedestrian crossing after intersection; passenger car turning right
F9	Pedestrian standing on the path of coming vehicle

Table 2: Description of the accident scenarios

2.2 Knowledge development

In the two most common car-pedestrian impact scenarios, the moving trajectories of the pedestrians and passenger cars were obtained directly from the definition of the scenarios. But the pedestrian speeds, the passenger car velocities and the locations of the body collision points on the cars are not recorded in STRADA. Therefore, the missed quantitative knowledge was estimated from the directly recorded information about the pedestrian ages, the road speed limits of the accident spots and the passenger car damages.

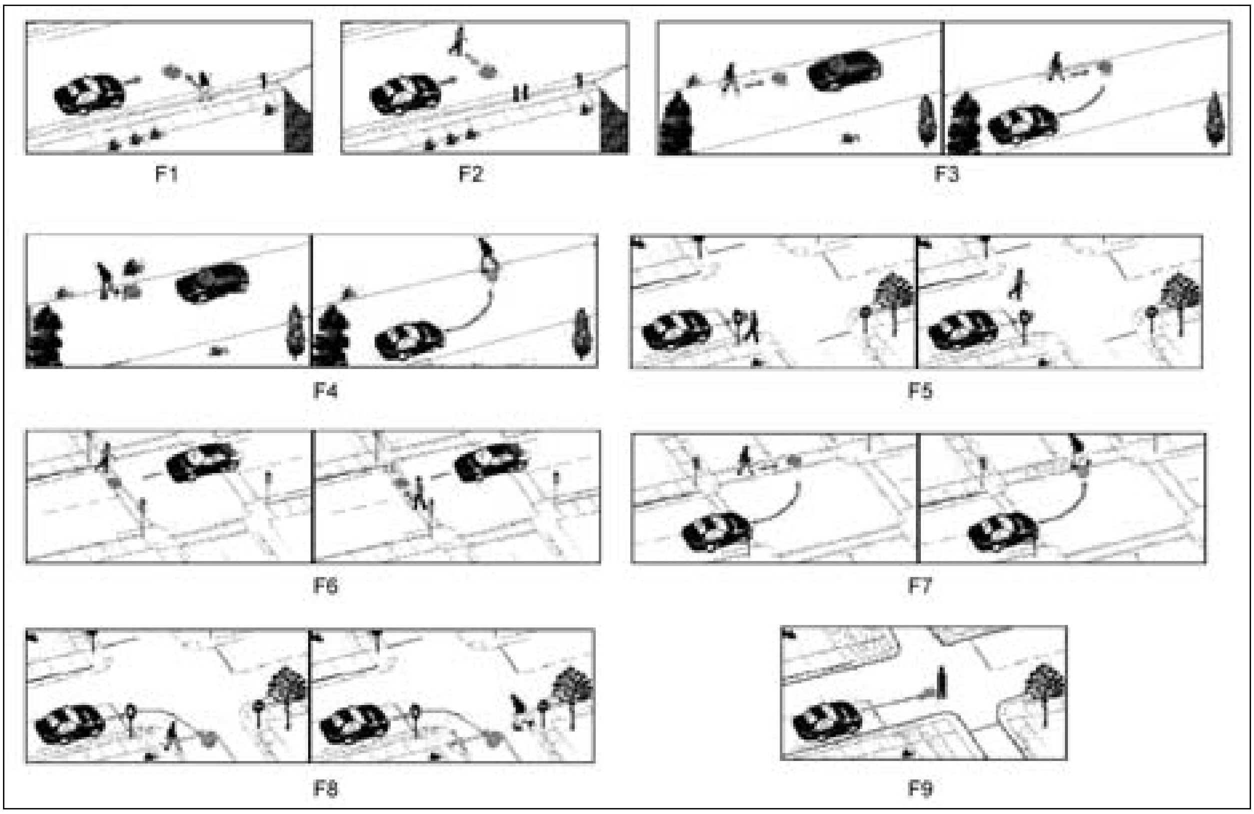


Figure 1: Passenger car-pedestrian impact scenarios in STRADA

2.2.1 Estimation of the pedestrian speeds

In the STARDA database, the pedestrian moving postures, such as walk or run, were not recorded. As a result, the pedestrian speeds were respectively estimated based on the hypothesis that all the pedestrians were impacted by cars while walking or the hypothesis that all the pedestrians were hit while running.

In the book "Pedestrian Accident Reconstruction and Litigation", the relationship between the pedestrian walking speed and the pedestrian age has been presented, as shown in Table 3 [4]. According to this relationship, the pedestrian walking speeds in the two accident scenarios were estimated.

In each of the scenarios, it was considered that the walking speeds of the pedestrians in each of the age groups listed in Table 3 should distribute in a normal distribution. The mean of this normal distribution was the 50th% speed for the age group. The standard deviation was calculated from the corresponding 15th% and 85th% speed. Using the speed normal distributions of the pedestrians in different age groups, the average 15th%, 50th% and 85th% speed of all the pedestrians were obtained by solving the equation below.

Pedestrian Age	Sample Size	Speed (m/s)		
		15th%	50th%	85th%
5-9	26	1.40	1.83	2.41
10-14	37	1.37	1.68	2.10
15-19	47	1.46	1.65	2.07
20-24	65	1.40	1.62	1.86
25-34	70	1.46	1.62	1.98
35-44	67	1.34	1.62	1.95
45-54	73	1.31	1.52	1.74
55-64	90	1.28	1.46	1.68
65+	67	1.07	1.28	1.46

Table 3: Pedestrian walking speeds for the different age groups

Pedestrian Age	Sample Size	Speed (m/s)		
		15th%	50th%	85th%
5-9	332	3.11	3.94	4.80
10-19	718	3.51	4.20	4.96
20-29	134	2.80	3.54	4.24
30-39	204	2.68	3.35	3.81
40-49	138	2.41	2.90	3.44
50-59	35	2.38	2.83	3.20
60+	30	2.04	2.47	2.71

Table 4: Pedestrian running speeds for the different age groups

$$N_t \times Per = \sum_{i=1}^{9} N_i \times Normdist(V_{per}, \mu_i, \sigma_i) \qquad (1)$$

Where N_t is the total number of the STRADA pedestrians; Per is percentage of the speed (15%, 50% or 85%); N_i is the number of the STRADA pedestrians in the ith age group in Table 3; Normdist is the cumulative normal distribution function of the pedestrian walking speed for the ith age group; V_{per} is the speed needed to be solved (the average 15th%, 50th% or 85th% speed); μ_i is the mean of the normal distribution and μ_i is the standard deviation of the distribution. It was then hypothesized that the walking speeds of all the pedestrians should also distribute in a normal distribution. The mean was chosen as the average 50th% speed and the standard deviation can be calculated from the average 15th% and 85th% speed. At last, a Chi-square test was used to validate this hypothesis.

Also in this book, the correlation between the pedestrian running speed and the pedestrian age, as indicated in Table 4 [4], has been researched. By the same method introduced above, the running speeds of the pedestrians in the two scenarios were estimated and validated.

2.2.2 Estimation of the car velocities

In the report "Speeds and Time Gaps", the car velocity relative to the road speed limit was investigated, as shown in Table 5 [5]. By the same method introduced in 2.2.1, the normal distributions of the car velocities in the most common accident scenarios were estimated and validated.

2.2.3 Estimation of the collision point locations

In the STRADA database, the car damage cases are distinguished with each other by the damage locations. If it is hypothesized that each damage case corresponds to a body collision point on the car, the locations of all the collision points can naturally be obtained.

Speed Limit (km/h)	Velocity (km/h)		
	2.5th%	50th%	97.5th%
30	29.3	34.5	39.7
50	51.0	52.4	53.8
70	67.3	68.4	69.5
90	87.9	88.9	89.9
110	110.2	111.4	112.6

Table 5: Car velocities with road speed limits

2.3 Establishment of the mathematical model

In this study, the sensor detective angle is a parameter which is already known. The shortest period from the pedestrian being detected by the sensor system to the protection system being totally deployed is another known parameter and is named the latency of the sensor and protection system. For each accident in the two most common scenarios, at the time of the latency period before the moment when the accident took place, the locations of the car and the pedestrian relative to the collision point can be calculated by their velocities and trajectories. Using the car location and the sensor detective angle, the sensor detective area on the pedestrian trajectory can be calculated. If this area covers the pedestrian, the sensor can detect the pedestrian on time. If not, the pedestrian will be missed by the sensor. While evaluating the sensor effectiveness in a whole accident scenario, the random distributions of the pedestrian speeds and car velocities can be used in the calculation. The obtained detective area and pedestrian location are also random variables. Using the density functions of them, the effectiveness of the sensor system can be calculated.

2.4 Sensor evaluation

Using the mathematical model, the sensor effectiveness for pedestrian detection was evaluated in the most common accident scenarios in terms of the different sensor detective angles. In this evaluation, it was hypothesized that all the pedestrians in the accident scenarios came from the right sides of the passenger cars. For each sensor detective angle, the evaluation was carried out respectively based on the hypothesis that all the pedestrians were impacted by cars while walking or the hypothesis that all the pedestrians were hit while running.

3 Results

3.1 Evaluation of the accident scenarios

Figure 2 shows the distribution of the nine passenger car-pedestrian impact scenarios. As indicated by it, F6 is the most common one. In this scenario, there are 647 car-pedestrian impacts which happened. They have occupied 30.9% of all the 2097 selected cases. In these accidents, 23 pedestrians were killed, 185 were seriously injured and 439 were slightly injured. F5 is the second most common scenario. In this scenario, 329 passenger car-pedestrian impacts were recorded, accounting for 15.7% of all the 2097 accidents. In these accidents, 3 pedestrians were killed, 80 were seriously injured and 246 were slightly injured.

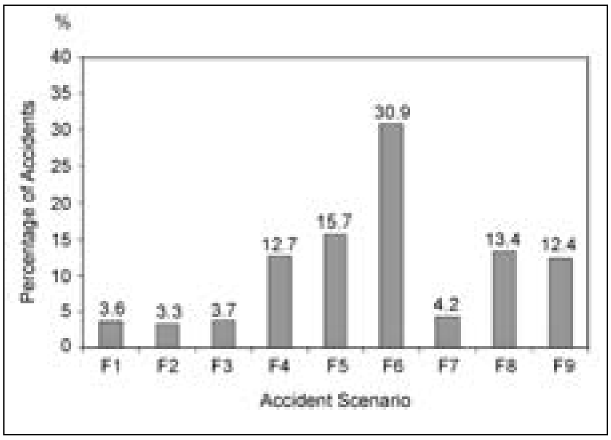


Figure 2: Distribution of the accident scenarios

Because F5 and F6 are the most common accident scenarios, the qualitative and quantitative knowledge was developed just for them.

3.2 Knowledge development based on the accident scenarios

3.2.1 Moving trajectories of the pedestrians and cars

According to the classification of the accident scenarios in STRADA, the moving trajectories of the pedestrians and cars were obtained directly. In these two scenarios, the moving trajectories of the pedestrians and passenger cars are straight and vertical to each other.

3.2.2 Pedestrian speeds

Figure 3 shows the age distributions of the pedestrians in F5 and F6.

As can be seen, 12.2% of the pedestrians in F5 and 17.8% in F6 are children (0<age<=14). 87.8% of the F5 pedestrians and 82.2% of F6 are adults.

If it was hypothesized that all the pedestrians in F5 and F6 were impacted by car while walking, the speed distributions of the pedestrians more than 4 years old, as shown in Table 6, were found by the method introduced in 2.2.1.

When it was hypothesized that all the pedestrians were hit while running, the speed distributions of

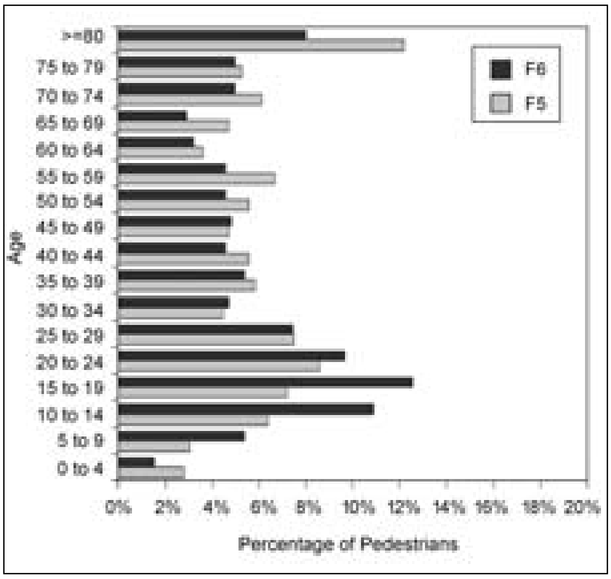


Figure 3: Distributions of the pedestrian ages

Accident Scenario	Mean (m/s)	Standard Deviation (m/s)
F5	1.48	0.29
F6	1.53	0.30

Table 6: Normal distributions of the pedestrian walking speeds

Accident Scenario	5-39 years old		Older than 40 years	
	Mean (m/s)	Standard Deviation (m/s)	Mean (m/s)	Standard Deviation (m/s)
F5	3.70	0.76	2.60	0.42
F6	3.80	0.78	2.61	0.42

Table 7: Normal distributions of the pedestrian running speeds

the pedestrians older than 4 years, as shown in Table 7, were respectively developed in two age groups of 5 to 39 years old and more than 40 years old so that they can pass the Chi-square test.

Validated by the Chi-square test, the normal distributions of the pedestrian speeds can be accepted on the significance level of 0.05.

3.2.3 Car velocities

As introduced in 2.2.2, the distributions of road speed limits, as shown in Figure 4, were used to estimate the car velocities in the accident scenario F5 and F6.

Based on Figure 4 and Table 5, the normal distributions of the car velocities in F5 and F6 were established, as indicated in Table 8. Validated by the Chi-square test, the normal distributions can be accepted on the significance level of 0.05.

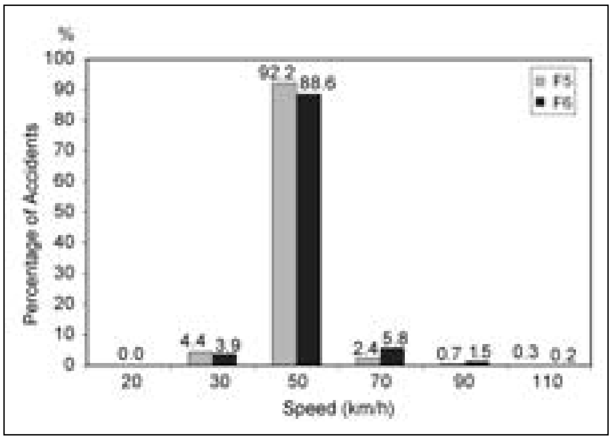


Figure 4: Distributions of the road speed limits

Accident Scenario	Mean (m/s)	Standard Deviation (m/s)
F5	52.4	8.5
F6	52.4	8.6

Table 8: Normal distributions of the passenger car velocities

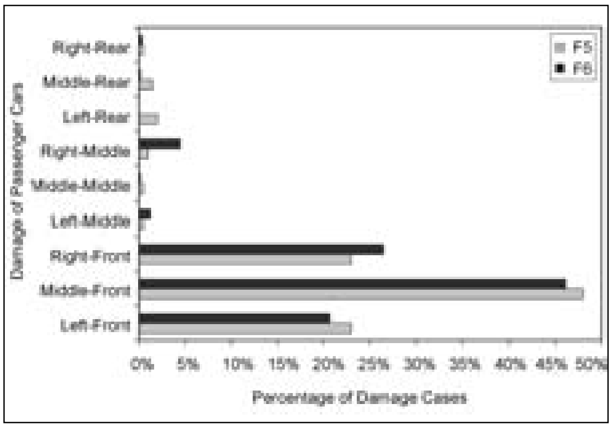


Figure 5: Distributions of the passenger car damage

3.2.4 Locations of the collision points on the cars

The distributions of the passenger car damage cases from F5 and F6 are shown in Figure 5.

As can be seen, the front structure of the passenger car is the most frequently damaged part. 94.0% of all the damage cases in F5 and 93.3% in F6 happened here.

Using the hypothesis presented in 2.2.3, the distributions of the collision point locations were estimated. According to the detective area of the sensor system, the damage cases which happened on the parts other than the car front were ignored. As a result, the distributions of collision point locations were obtained, as shown in Table 9.

Accident Scenario	Left-Front	Middle-Front	Right-Front
F5	24.5%	51.0%	24.5%
F6	22.2%	49.4%	28.4%

Table 9: Distributions of the collision point locations

3.3 Mathematical model for the sensor evaluation

Based on the developed qualitative and quantitative knowledge of the accident scenario F5 and F6, the mathematical model, as shown in Figure 6, was developed to evaluate the sensor effectiveness.

For any case covered by this model, D_c can be calculated by

$$D_c = V_c \times T_r \quad (2)$$

Where V_c is the car velocity and T_r is the latency of the sensor and protection system. D_p can be calculated by

$$D_p = V_p \times T_r \quad (3)$$

Where V_p is the pedestrian speed. D_s and Y_p can then be obtained by

$$D_s = V_c \times \tan(\alpha) \quad (4)$$

$$Y_p = V_p - Y_c \quad (5)$$

If Y_p is smaller than D_s, the sensor system can detect the pedestrian on time.

If the sensor effectiveness in the whole accident scenario F5 or F6 needs to be evaluated, the density functions of the car velocities and pedestrian speeds can be used in Equation (2) and (3) as V_c and V_p. Y_c is also a random variable. According to Equation (4) and (5), Y_p and D_s are the functions of these random variables. The sensor effectiveness for pedestrian detection can therefore be calculated by

$$P = 1 - \int_0^{\infty} Y_p(x) \int_0^{x} D_s(y)\,dy\,dx \quad (6)$$

Where P is the probability of the pedestrian being detected on time by the sensor system, $Y_p(x)$ and $D_s(y)$ are the density functions of Y_p and D_s.

3.4 Evaluation of the sensor system

According to the analysis of the collision point locations in 3.2.4, the body collision points were concentrated on the left, middle and right front points of the passenger cars. If the width of the passenger cars was set as 1.8m, the distributions of Y_c were obtained as shown in Table 10.

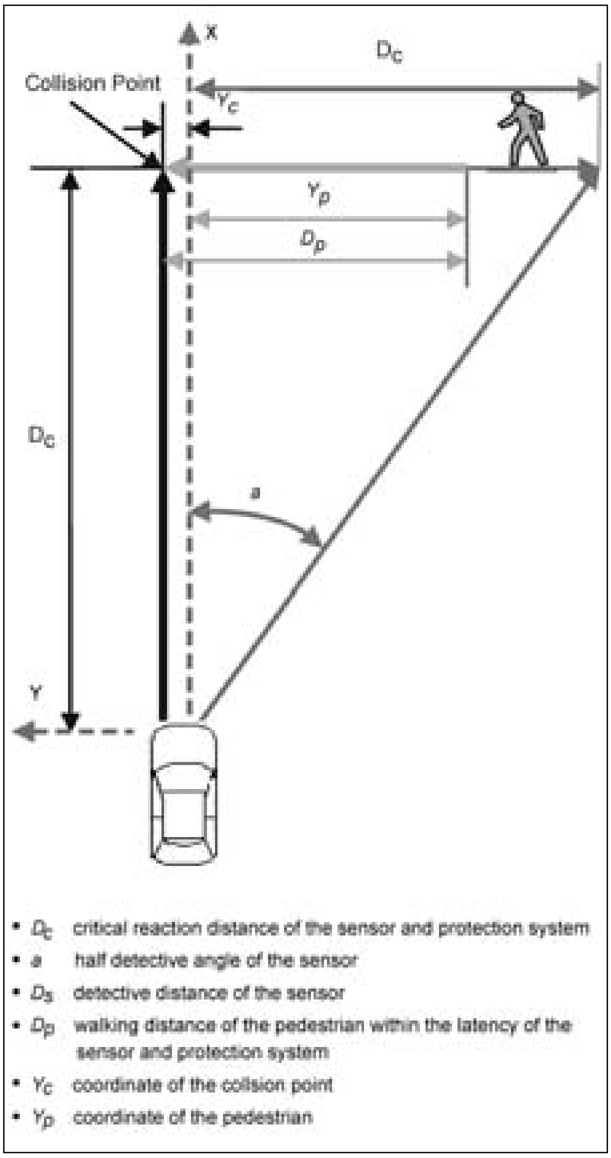


Figure 6: Mathematical model for the sensor evaluation

Accident Scenario	Y_c		
	-0.6m	0m	0.6m
F5	24.5%	51.0%	24.5%
F6	28.4%	49.4%	22.2%

Table 10: Distributions of the Y-coordinates of the collision points

All the pedestrians in F5 and F6 were considered coming from the right side of the cars. If it was assumed that T_r was 510ms, for each Y_c value listed in Table 10, the normal distributions of Y_p, as indicated in Table 11, were calculated by Equation (3) and (5).

Y_c (m)	Accident Scenario	Yp					
		Mean (m)			Standard Deviation (m)		
		Pedestrian Walking	Pedestrian Running		Pedestrian Walking	Pedestrian Running	
			5–39	40+		5–39	40+
-0.6	F5	1.36	2.49	1.93	0.15	0.39	0.21
	F6	1.38	2.54	1.93	0.16	0.40	0.22
0	F5	0.76	1.89	1.33	0.15	0.39	0.21
	F6	0.78	1.94	1.33	0.16	0.40	0.22
0.6	F5	0.16	1.29	0.73	0.15	0.39	0.21
	F6	0.18	1.34	0.73	0.16	0.40	0.22

Table 11: Normal distributions of Y_p

Alpha (degrees)	Accident Scenario	D_s	
		Mean (m)	Standard Deviation (m)
45	F5	7.42	1.20
	F6	7.43	1.22
30	F5	4.29	0.69
	F6	4.29	0.70
15	F5	1.99	0.32
	F6	1.99	0.33

Table 12: Normal distributions of D_s

Alpha (degrees)	Accident Scenario	P	
		Pedestrian Walking	Pedestrian Running
45	F5	1.000	1.000
	F6	1.000	1.000
30	F5	1.000	0.998
	F6	1.000	0.997
15	F5	0.991	0.734
	F6	0.987	0.657

Table 13: Possibility of the pedestrians being detected on time

If alpha was chosen as 45, 30 and 15 degrees, the normal distributions of D_s, as indicated in Table 12, were calculated by Equation (2) and (4).

Using Equation (6) and the conditional probability theory, the P values shown in Table 13 were calculated.

4 Discussions

In the classification of the STRADA accident scenarios, the pedestrian trajectory, the car trajectory and the accident location are the basic traffic elements which are used to differentiate the accident scenarios. In the three traffic elements, the accident location – roadway or intersection – is the primary factor which is used to distinguish the different accident scenarios. The pedestrian trajectory is the secondary most important factor while the passenger car trajectory is comparatively less important in the classification. This classification has a certain drawback. The major problem is that some accidents in which the cars have obviously different moving trajectories are classified into the same accident scenario. For example, the accidents in which the passenger car turns are categorized into the accident scenario F3 with the accidents in which the passenger car goes straight ahead. This problem makes the discrimination of the car trajectories in the accident scenario F3 and F4 impossible.

As can be seen from Table 13, the P values in this study were calculated respectively for walking and running pedestrians. In fact, the actual P values are smaller than the calculated results for walking pedestrians and larger than the results for running pedestrians.

Although not recorded in the STRADA database, in many passenger car-pedestrian accidents, the drivers braked the cars before the collisions. In such cases, D_c should be calculated in consideration of the car deceleration. As a result, in comparison with the same conditions but where the driver did not brake, D_c will be shorter and D_s will be smaller. This will raise the requirement of a larger sensor detection angle. In the mathematical model developed in this study, this situation is not considered. Therefore, the effectiveness of the sensor system can be overestimated.

If the pedestrian visibility is obstructed, the effectiveness of the sensor system can still be calculated by the mathematical model. However, in this case, the sensor system will fail to detect the pedestrian on time not only when Y_p is larger than D_s but also when Y_p is larger than the Y-coordinate of the obstruction object. Because the pedestrian visibility is not recorded in STRADA, this situation is not considered in this study and the effectiveness of the sensor system can therefore be overrated.

5 Conclusions

Among the nine car-pedestrian impact scenarios in STRADA, F5 is the second most common one. If the half sensor detective angle Alpha is equal to or larger than 30 degrees, almost all the pedestrians in this scenario can be detected on time. If the alpha angle is 15 degrees, 99.1% of the walking pedestrians and 73.4% of the running pedestrians can be detected. F6 is the most common scenario. When the alpha angle is equal to or larger than 30 degrees, all the pedestrians in this scenario can be detected on time. But if the angle is 15 degrees, only 98.7% of the walking pedestrians and 65.7% of the running pedestrians will be detected. In order to detect all the pedestrians in the scenario F5 and F6 on time, the detective angle of the sensor system (twice the alpha angle) must be kept larger than 60 degrees.

Acknowledgment

This study is sponsored by the Intelligent Vehicle Safety Systems (IVSS) Programme, Sweden.

References

1. L.J. SCHOFER, K.K. CHRISTOFFEL, M. DONOVAN, V.J. LAVIGNE, R.R. TANZ, E.K. WILLS (1995): Child Pedestrian Injury Taxonomy Based on Visibility and Action, Accident Analysis and Prevention, Vol. 27, No. 3, pp. 317-333

2. C.J .STUTTS, W.W. HUNTER, E.W. PEIN (1996): Pedestrian-Vehicle Crash Types: An Update, Transportation Research Record, Issue 1538, pp. 69-74

3. Swedish Road Administration (2005): Swedish Traffic Accident Data Acquisition, Sweden

4. J. EUBANKS, F.P. HILL, A.D. CASTEE I(2004): Pedestrian Accident Reconstruction and Litigation, 2nd ed, Lawyers & Judges Publishing Company, Tucson, Arizona, U.S.A.

5. A.C. SVEDUNG (2005): Speeds and Time Gaps, Swedish Road Administration, http://www.vv.se/, Sweden

C. Haasper, D. Otte, K. Knobloch, C. Probst,
C. Krettek, M. Richter
Trauma Department/Accident Research Unit,
Hannover Medical School (MHH), Hannover,
Germany

A Medical and Technical Analysis of Knee Injuries Focusing Vulnerable Road Users and Restrained Car Drivers in Road Traffic

Abstract

Description of road traffic related knee injuries in published investigations is very heterogeneous. The purpose of this study was to estimate the risk of knee injuries in real world car impacts in Germany focusing vulnerable road users (pedestrians, bicyclists and motorcyclists) and restrained car drivers.

The accident research unit analyses technical and medical data collected shortly after the accident at scene. Two different periods (years 1985-1993 and 1995-2003) were compared focusing on knee injuries (Abbreviated Injury Scale (AIS_{Knee}) 2/3). In order to determine the influences type of collision, direction and speed as well as the injury pattern and different injury scores (AIS, MAIS, ISS) were examined.

1.794 pedestrians, 742 motorcyclists, 2.728 bicyclists and 1.116 car drivers were extracted. 2% had serious ligamentous or bony injuries in relation to all injured. The risk of injury is higher for two-wheelers than for pedestrians, but knee injury severity is higher for the latter group. Overall the current knee injury risk is low and significant reduced comparing both time periods (27%, p<0,0001). Severe injuries (AIS_{Knee} 2/3) were below 1%). Improved aerodynamic design of car fronts reduced the risk for severe knee injuries significantly (p=0,0015). Highest risk of injury is for motorcycle followed by pedestrians, respectively. Knee protectors could prevent injuries by reducing local forces. The classically described dashboard injury was rarely identified.

The overall injury risk for knee injuries in road traffic is lower than estimated and reduced comparing both periods. The aerodynamic shape of current cars compared to older types reduced the incidence and severity of knee injuries. Further modification and optimization of the interior and exterior design could be a proper measurement. Classic described injury mechanisms were rarely identified. It seems that the AIS is still underestimating extremity injuries and their long term results.

Introduction

Description of road traffic related knee injuries is very heterogeneous. The purpose of this study was to estimate the risk of knee injuries in real world car impacts in Germany focusing vulnerable road users (pedestrians, bicyclists and motorcyclists) and restrained car drivers. With the increasing use of safety belts and availability of air bags, more occupants survive serious car crashes [14]. However, many people involved in frontal or offset crashes incur disabling lower extremity injuries [23, 22, 21]. Though lower extremity injuries are usually not life threatening, the physical and psychosocial consequences of lower extremity injuries are often long lasting. Next to the high risks subsequently high costs follow lower limb injuries [27, 18, 12]. The knee is the largest and one of the most complicated joint of the human body. Eight joint parts cooperate here and allow a limited rotation around its longitudinal axis besides extension and flexion of the lower extremity. Two cruciate and two collateral ligaments stabilize the knee passively. The menisci counterbalance the different bone surfaces. In case of an injury of the knee, one or more of these ligamental or bony elements can be injured and the probability of long-term problems is high due to the complexity [9]. In case of an crash event with a knee injury there is a high likelihood of residual long-term effects [8].

YANG [26] reported in a study using a mathematical simulation of knee movements different injury patterns of the leg. Fractures of the tibia and/or knee injuries such as ruptures of the ligaments and fractures of the condyles were frequently found in experimental studies; he mentions studies by BUNKETORP, ALDMAN, KRAMER, PRITZ and CAVALLERO [2, 10, 11, 16, 20]. Also accident analyses report knee injuries by APPEL, ASHTON and MAKI [3, 17, 4]. A study carried out in Dublin found in a post mortem investigation at the Department of Forensic Medicine, knee joint injuries in 214 out of 357 fatal pedestrian victims of traffic accidents (60%) [25]. Although there are previous studies trying to outline distinct characteristics there is a lack of in-depth technical evaluation for preventive interventions. Most of the previous study analyzed medical, police, and/or insurance records [6, 7, 15, 5]. Under consideration of the results of previous studies with other priorities, we strongly believe that a technical in-depth crash investigation in combination with a medical data analysis is the most sufficient basis for an improvement of safety lower limb injury risk.

The purpose of this study was to analyze the incidence of road traffic knee injuries in Germany by demographic data, place and person co-ordinates and to identify clusters.

Methods

The accident research unit analyses technical and medical data collected shortly after the accident at scene. Two different periods (years 1985-1993 and 1995-2003) were compared focusing on knee injuries (Abbreviated Injury Scale (AIS_{Knee}) 2/3). In order to determine the influences type of collision, direction and speed as well as the injury pattern and different injury scores (AIS, MAIS, ISS) were examined. The vulnerable road users were distinguished as pedestrians, motorcyclists and bicyclists.

n=16563 accidents with 22804 injured persons were identified (Table 1). A total of, 11111 accidents of all traffic participants for the years 1985 to 1994 and 11693 accidents for the years 1995 to 2003 (current situation) were available. From these cohorts the injury frequency of the knee for different types of traffic participation (occupants of cars and trucks, vulnerable road users) including the slight soft tissue injuries were determined in this study.

For vulnerable road users two different groups of accident data were compared, in which a car hits a vulnerable road user: the years 1985 to 1993 (n=2739 persons), and 1995 to 2003 (n=2749 persons). The vulnerable road users were differentiated as pedestrians (n=1794), motorcyclists (n=742) and bicyclists (n=2728). Only those accidents were selected that involved cars (vans included). For the same periods restrained car drivers were selected (n=591 vs. n=525). The accidents with injuries to the knee were compared to all accidents of traffic participants.

Accident reports collected between 1985 and 2003 were carefully analyzed for knee injured road traffic participants and the following parameters: demographic data, AIS, MAIS, ISS, incidence of polytrauma, incidence of serious or severe injuries, role of traffic participation, collision speed, collision opponent, and collision type. For statistical analysis of the correlation between crash circumstances with injury severity (AIS, MAIS, ISS) a t-, Pearson- or Linear-Trend-test was used. The classification of the injury severity was executed according to AIS (American Association for Automotive Medicine 1998 [1]). The documentation was conducted using the same methodology for the whole period of data collection, which allowed for a statistical comparison of the accident structure between early cases and today. These cases were checked by an experienced surgeon based on the AIS-classification and the medical evaluation of the injury pattern and injury patterns of the knee were defined. Knee injuries examined in this study were defined from the distal femur epiphysis including condyles to the tibial head with epiphysis, as well as all ligaments including bone insertion, menisci and the patella and the soft tissue surrounding these structures. The AIS classification considers contusions and smaller soft tissue lesions as AIS 1, soft tissue injuries of a greater extent (sprains) with injuries of bursa, ligaments or menisci, patella fractures, non-compound and only slightly shifted fractures of the tibia, knee dislocations and an open joint are allocated AIS degree 2 whereas fractures of the distal femur, compound or comminute proximal tibia fractures, full posterior cruciate ligament ruptures and open ligament ruptures are classified as the highest degree of injury severity AIS 3 (Table 2). Different technical parameters were focused and examined like influence of car shape developments on injury, the severity outcome of the knee injury pattern in vulnerable road users and finding the characteristics and mechanisms of knee joint injuries. An evaluation concerning the occurring mechanics that were operative during the impact and subsequently applied to the knee unit was conducted. For this purpose, the position of the pedestrian or the cyclists that was derivable from the reconstruction of the accident was taken into account and the resulting kinematics were determined from the damage to the vehicle and the evaluated throwing motion and differentiated according to the occurring load characteristics as direct impact, bending, rotation and combinations of these. A comprehensive reconstruction of the

	total	kind of traffic participation				
		car occupant	truck occupant	motorcyclist	bicyclist	pedestrian
Year of accident 1985-1993						
Total (n)	11111	5891	401	1052	2304	1463
Head	47.7%	48.1%	51.3%	23.2%	52.3%	55.8%
Neck	19.9%	33.1%	22.2%	7.8%	4.9%	4.1%
Thorax	29.8%	37.6%	24.6%	22.5%	20.9%	22.0%
Upper extr.	37.1%	28.0%	36.9%	49.2%	47.6%	44.4%
Abdomen	8.2%	9.0%	8.1%	7.7%	6.3%	8.8%
Pelvis	10.7%	7.8%	7.4%	16.0%	12.2%	16.3%
Femur	9.2%	4.8%	7.8%	16.9%	12.1%	15.5%
Knee	23.5%	14.4%	22.0%	42.2%	31.5%	30.9%
Lower leg	16.0%	9.0%	13.0%	29.0%	20.9%	25.7%
Foot	13.2%	7.1%	7.9%	29.6%	17.2%	18.2%
Year of accident 1995-2003						
Total (n)	11693	6824	507	1227	2018	1117
Head	36.6%	35.1%	45.0%	17.0%	42.1%	52.8%
Neck	30.2%	46.7%	38.1%	7.5%	5.6%	4.9%
Thorax	27.6%	31.2%	32.9%	26.3%	20.5%	19.9%
Upper extr.	31.3%	22.4%	42.8%	45.0%	44.3%	37.4%
Abdomen	6.8%	6.7%	15.5%	6.9%	5.1%	7.4%
Pelvis	8.2%	5.0%	12.1%	14.6%	10.7%	13.4%
Femur	4.7%	2.5%	5.1%	9.4%	6.6%	8.7%
Knee	17.2%	10.0%	16.6%	36.1%	25.4%	21.8%
Lower leg	9.6%	5.0%	10.6%	17.6%	14.6%	17.6%
Foot	7.7%	3.3%	4.9%	17.6%	12.7%	14.1%

Table 1: Distribution of injuries in selected road traffic users

AIS Knee	
1	Contusion
2	Soft tissue injuries incl. ligaments, menisci; patella fractures; closed, minimal displaced tibial fractures; knee dislocation; opened joint cavity
3	Fractures of the distal femur; open, displaced or multifragmentary tibial fractures

Table 2: AIS Knee (based on AIS 1998)

vehicle motion sequence and the accident severity that occurred can be determined on the basis of scaled drawings and a technical impact analysis. Accident characteristics, such as delta-v, EES or deformation depth can be correlated to the classified injury severities. The injuries were documented using independent documentation and the inspection of medical diagnosis reports and x-rays. The documentation contains graphical material and drawings of the accident traces at the site of the accident, detailed measurements of the damages to the vehicle are taken and an accident reconstruction of the motion sequence using computer aided simulation (PCcrash) is conducted. From these data the origin, the type and the extent of the injuries can be determined. The analysis of the accident mechanism and the accident load from the technical point of view is conducted in parallel, based on the analysis of technical data photographs.

Results

1.794 pedestrians, 742 motorcyclists, 2.728 bicyclists and 1.116 car drivers were extracted (Table 1).

Car occupants

After grouping in the years 1985-1993 and 1995-2003 all cases of knee injuries with a severity of AIS 2+ were separated (85-93 n=56; 95-03 n=26). The injuries during the impact and afterwards to the knee were evaluated. End position of the knees of the seated occupants that had been derived from the accident reconstruction was taken into account and the occurring kinematics were evaluated according to the resulting damages in the interior as well as the impact vector and the resulting relative

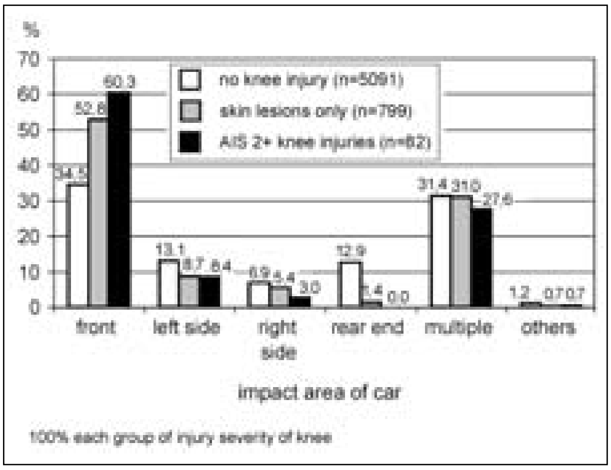


Figure 1: Impact area of restrained car drivers; n=5972 belted injured car drivers

motion of the car (Figure 1) and differentiated according to frontal and side impact it could be demonstrated that an increasing delta-v the incidence of a knee injury and the degree of severity increases.

Up to delta-v values of 50km/h the portion of knee injuries AIS 2+ could be seen in less than 6%. In frontal collisions with a delta-v of up to 20km/h only 0.6% of the drivers suffered from knee injuries AIS 2+ and 13.3% AIS 1, for delta-v from 41 to 50km/h 3.5% AIS 2+ and 25.2% AIS 1 occurred. For side impacts knee injuries of the degree of severity AIS 2+ occurred only in cases of a high accident severity with more than 40km/h delta-v, for a delta-v 41 to 50km/h they registered at 3.0%. 80% of the delta-v values of restrained drivers with knee injures AIS 2+ could be found above delta-v 30 m/h, whereas for drivers without knee injuries 80% of all collisions occurred at delta-v values of up to 40km/h. Whereas 5.1% of the passenger car drivers suffered slight knee injuries AIS 1 and 3.2% of those not injured at the knee had an overall MAIS 3+ injury severity, 54.7% of the drivers who were injured AIS 2+ at the knee suffered from injuries of a degree of severity MAIS 3 or higher. It was remarkable that persons suffering from severe knee injuries as opposed to persons with a slight knee impact trauma AIS 1 and the collective of those occupants of cars in accidents who were not injured at the knee, the proportion of so-called whiplash injuries of the neck occurred significantly less frequently (33.4%, 46.2% compared to 12.8%), whereas all other body regions were more severely injured with increasing severity of the knee injuries. The pelvis was injured four times as frequently in persons with AIS 2+ knee injuries than for passengers/drivers without knee injuries, arm and head and abdomen are injured double frequently. Three quarters of all AIS 2+ knee injured restrained car drivers suffered a fractures of the patella (32.5%) and of the head of the tibia (22.1%) as well as tendon ruptures (24.2%). Fractures of the femur condyles were found in 9.3% of the cases. Where ligament injuries were observed, the medial collateral ligament (11.2%) was affected more frequently than the lateral collateral ligament (2.2%) and the anterior cruciate ligament (10.1%) more frequently than the posterior cruciate ligament. Lateral und medial menisci were injured only in 0.8% of the cases. Severe knee injuries were connected to an intrusion into the passenger compartment. In frontal impacts of cars 43% of the vehicles of restrained drivers with AIS 2+ knee injuries showed an intrusion of the compartment and 32.7% in lateral collisions, in contrast to only 14% of those with light AIS 1 soft tissue lesions of the knee and to only 7.4% of those who were not injured at the leg (16.3% or 12% for a lateral deformation). Intrusion seems to play an important role in the occurrence of severe injuries to the knee. 70% of the cars of the persons with knee injuries AIS 2+ suffered an intrusion at delta-v above 40km/h comparing to those without intrusion where nearly 2/3 delta-v values can be seen up to 40km/h. OF car occupants having severe knee injuries AIS 2+ only 54.7% did not suffer from accompanying injuries of the lower leg, foot, thigh and pelvis. 22.8% suffered from a fracture of the thigh, 13% of the pelvis, 18.8% of the lower leg, 9.6% of the foot and ankle and 0.9% of the hip. Patella fractures are accompanied in 27.1% of the cases by femur fractures und in 18.2% by fractures of the lower leg. The area of the foot is still relatively frequently injured at 11.7%. Ligament injuries frequently also involve injuries of the lower leg or foot. Collateral ligament lesions (medial as well as lateral) were linked with pelvis injuries (30%/50%). This characterizes the extreme torsion of the foot and lower leg resulting in tensile loads in the ligament structures of the knee. Thus severe knee injuries were correlated to intrusions of the passenger compartment in 32.7% of the cases. Patella fractures, fractures of the femur condylus and tendon ruptures could be observed starting at delta-v 20km/h. While restrained car drivers without any knee injury had a mean delta-v value of 29.4km/h and those with knee soft tissue lesions AIS 1 had 37.8km/h, all kinds of knee injuries AIS 2+ occurred with higher accident severity of mean delta-v of

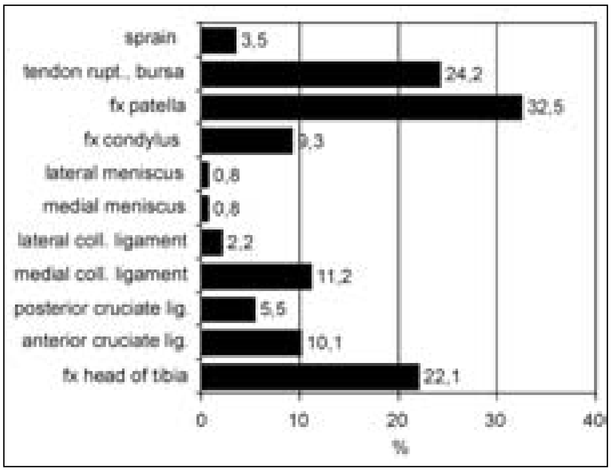


Figure 2: Knee injuries of restrained car drivers

46.1km/h (tibia plateau fracture) until mean delta-v of 60.3km/h for medial collateral ligament lesions. Remarkable seems the fact that ligament injuries of the cruciate and collateral structure of the knee higher load was responsible than for the bony fractures of the head of tibia, condylus and patella (Figure 2). A comparison of airbag and non airbag cases demonstrated a higher risk for knee injuries with airbag deployment. Especially for higher delta-v >30km/h a significant higher portion of AIS 1 knee injuries can be established by 25% for delta-v 31-40km/h and 142% for delta-v 41-50km/h.

Vulnerable road users

Highest frequency of knee joint injuries can be established for motorized two-wheelers, i.e. 42% of motorcyclists suffered knee injuries in accidents 1985-1993 compared to 36% in 1995-2003. The lowest frequency was in pedestrians, where 22% were injured at the knee in the course of accidents in 1995-2003. In case of a serious injury (AIS 2/3) for pedestrians, fractures of tibia head can often be observed (50.8%), for motorcyclists, tendon ruptures and ruptures of frontal cruciate ligament are very frequent (36.7%/20.9%).

If the investigation would be limited to bony and ligamentous injuries of the knee area, such injuries occur in less than 3%. They occur currently (1995 to 2003) at 1.2% of the pedestrians (formerly 2.6%), at 0.5% of the bicyclists (formerly 0.8%) and 1.6% of the motorized two-wheelers (formerly 1.9%).

70% of all measured impact velocities rated between 20 and 60km/h of the car, for pedestrians as well as bicyclists, whereas for patients without knee injury they rated 10 to 50km/h. For motorcyclists 70% of the determined relative velocities were found to be between 20 and 75km/h, these occurred for motorcyclists with knee injuries at 30 to 90km/h. Thus the impact speed is a dominant predictor for knee injury risk and is following in more injury severity of the whole human body. The resulting severity of the injuries of patients with knee injuries was significantly higher. Only 45.6% of the persons with knee injuries were assigned with a rate for minor injury MAIS 1 and 25.4% had a MAIS 3+ (without knee injuries 9.7%).

In case of a severe knee injury motorcyclists suffer more frequently than other road users ruptured tendons of the bursa (36.7%) and the anterior cruciate ligaments (20.9%), whereas pedestrians frequently suffer from tibia plateau fractures (50.8%) and medial ligamental lesions (20.7%). Injured bicyclists frequently show fractures of the patella (17%) and of the tibial plateau (27.2%). Injuries of the condylus, of the meniscus and the lateral ligaments were detected relatively rarely, especially for bicyclists.

Pedestrian impacts

A high risk for knee injuries arises obviously in the case of an impact of a car to the right side of a body because this situation leads to high loads to the knee elements (Figure 3). Where 32.6% of all pedestrians with no knee injuries had an impact from the right, 45% of all pedestrians who suffered from injuries to ligaments and bones of the knee were hit from the right. Such an overrepresentation was not apparent for the other sides of impact. It was differentiated if the struck sided knee was injured or the opposite one. For this analysis all laterally collided pedestrians and bicyclists with knee injuries were put together and found that sprains (86.2%), outer meniscus lesions (100%), fractures of condylus (73.7%) and of tibia head (74.8%) mostly linked with the struck side. In contrast, fractures of patella (34.4%) and medial meniscus lesions (48.6%) and tendon ruptures (40.5%) were often injured on non-struck side of the legs. It can be seen in the diagram that the highest frequent injury location for the non-struck sided knee can be registered for inner ligament lesions (31%) and for the struck side fractures of head of tibia can be seen in 40.4%.

Bicycle impacts

60.9% of all collisions between cars and bicycles resulting in an osseous/ligamentary knee injury

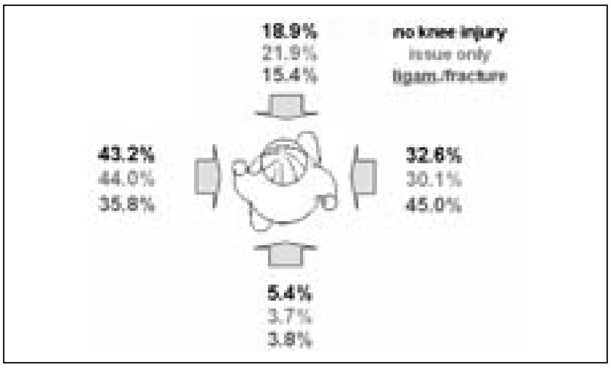


Figure 3: Impact directions of pedestrians comparing persons with and without knee injuries

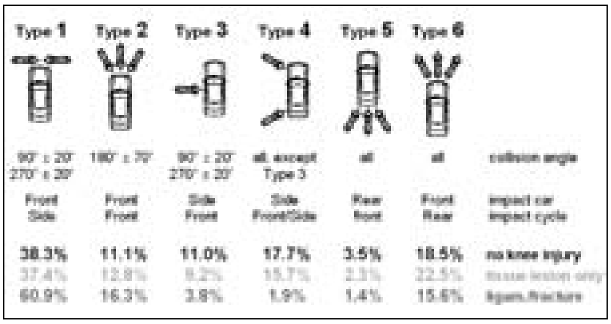


Figure 4: Collision configurations of bicycle to car impacts comparing victims with and without knee injuries

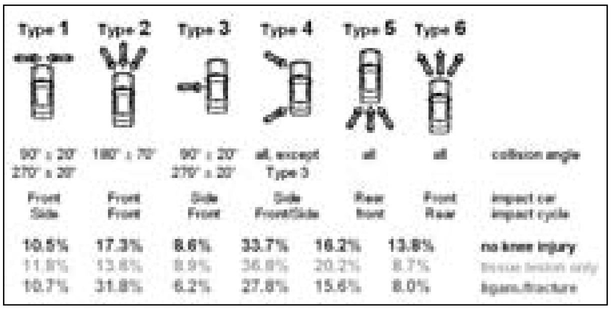


Figure 5: Collision configurations of motorcycle accidents compared victims with and without knee injuries

occur at near right angles, where the front end of the vehicle hits the side of the bicycle (Figure 4). In contrast, this type collision configuration occurs only at 38.7% of all bicyclist accidents without knee injury and in 37.4% of bicyclists with tissue lesions only.

Motorcycle impacts

For motorcyclists the angled to frontal impact of the motorcycle to the front of the car seems to be especially dangerous where osseous/ligamentous knee injuries (31.8% of all persons with knee injuries in comparison to 17.3% without knee injury) were observed (Figure 5). In contrast, the exactly perpendicular impact of a car front against the side of the motorcycle does not seem to increase the risk for knee injuries. This type of head on collisions constitutes 8.9% of all collision situations of the motorcycle driver against a car, this type of collision was also present for those 6.2% that suffered only bony of ligamentous injuries of the knee. It was apparent that for bicyclists and pedestrians the simple distortions and injuries of the outer meniscus and the outer ligaments occur at rather lower velocities, whereas motorcyclists suffer them at rather higher speeds. Injuries of the medial ligaments and tibia plateau fractures for the latter occur at lower impact speeds, however. Tendon ruptures and bursa injuries seem significantly related to higher velocities.

Mechanisms vulnerable road users

A direct impact force was responsible in 31.2%, in 9.6% bending and in 5% rotation can be seen as mechanisms (Figure 6). In 41.7% a combination of direct force plus bending could be established in

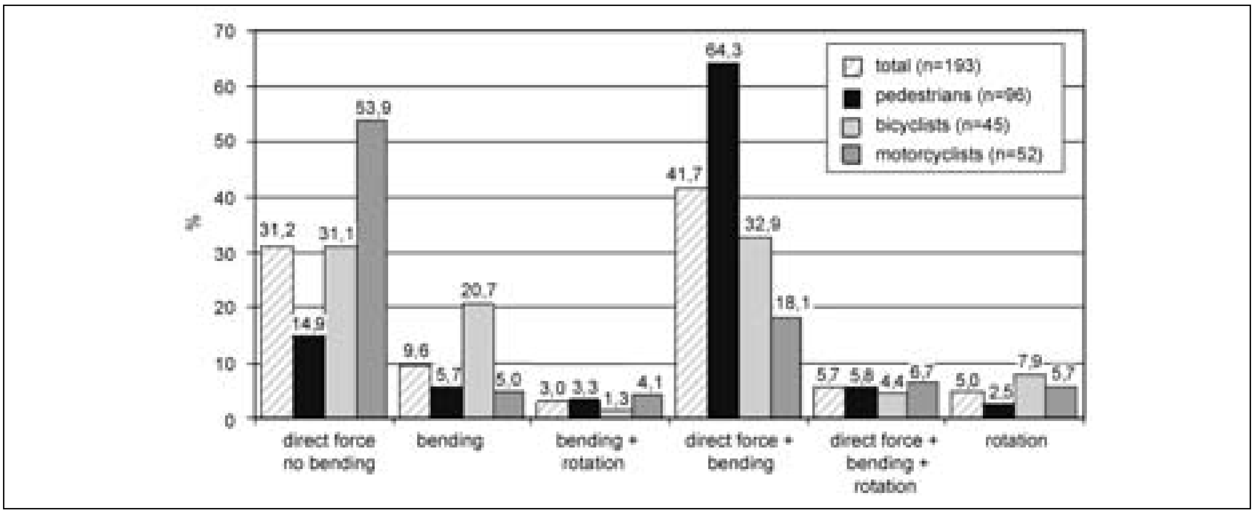


Figure 6: Mechanisms of knee injuries in vulnerable road users

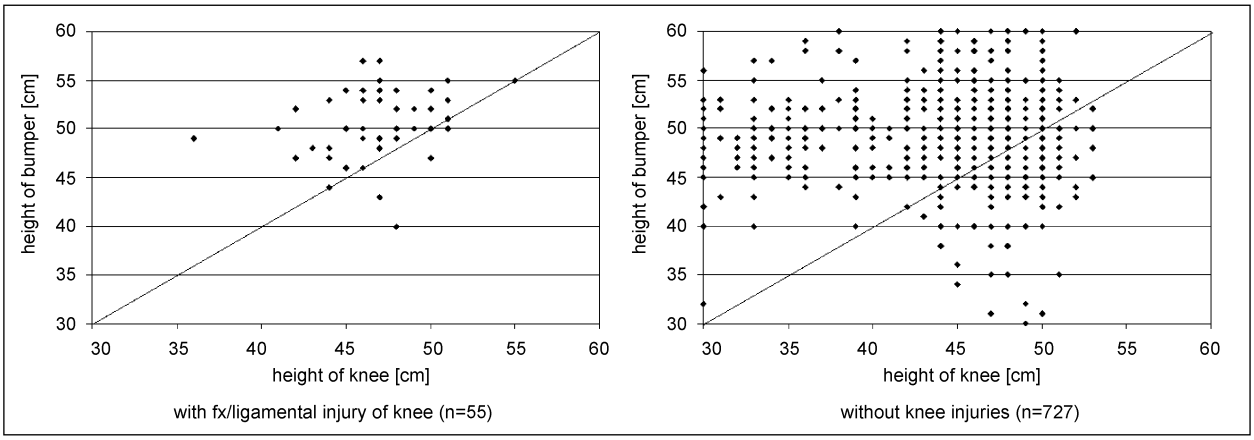


Figure 7: Bumper height and knee height for pedestrian accidents comparing persons with and without knee injuries

many cases. A difference in the collisions of the individual types of traffic participants was noted. Pedestrians frequently suffered at 64.3% from direct force and bending, whereas motorcyclists at 53.9% frequently suffered from direct force without bending. Knee injuries based on isolated rotation was in contrast detected relatively infrequently. In most of the cases rotation occurred together with bending.

It is remarkable that a lateral impact results very often in a tibia plateau fracture. This can be seen especially in car to pedestrian accidents but also in car to bicycle collisions and can be opposed to many studies, claiming that a valgus stress and an increase in force to the medial collateral ligament, which in turn then tears, occur. The analyzed mechanism for the tibia plateau fracture is related mainly to a lateral impact with bending of the ligaments. In the course of the accident, the medial collateral ligament seems to last and the increase in force seems to lead to pressure on the lateral compartment, i.e. the femur condylus is pressed on the tibial plateau while the medial collateral ligament resists, resulting in a tibia plateau fracture. Therefore 16.2% of the lateral collided cyclists with knee injuries suffered a tibia plateau fracture and 40.4% of the pedestrians suffered this kind of injury on the struck sided leg. This can be confirmed by the resulting severity of the tibia plateau fracture according to Schatzker 1 to 3 that represents two third of all kind of tibia plateau fractures.

The height of the bumper seems to have some sort of influence on the development of osseous and/or ligamentary knee injuries (Figure 7). If the bumper induces energy in the area of the knee or above it, knee injuries are extremely significant. Only few cases were found where a knee injury has occurred and the bumper was situated below the knee. 2% had serious ligamentous or bony injuries in relation to all injured. Improved aerodynamic design of car fronts reduced the risk for severe knee injuries significantly (p=0,0015).

The risk of injury is higher for two-wheelers than for pedestrians, but knee injury severity is higher for the latter group. Overall the current knee injury risk is low and significant reduced comparing both time periods (27%, p<0,0001). Severe injuries (AIS_{Knee} 2/3) were below 1%). Highest risk of injury is for motorcycles followed by pedestrians, respectively. The classically described dashboard injury was rarely identified.

Conclusion

The overall injury risk for knee injuries in road traffic is lower than estimated and reduced comparing both periods.

Most of the authors reported on risk of knee injuries for unrestrained situations. Lower limb injuries occurred to front seat occupants in more than one in three head-on crashes involving casualties. A classically mechanism described by SANDERS [24] is known as the “dashboard injury”. Axial load after contact with the instrument panel results in complex knee-femur-hip injuries. Those are patella fractures, posterior cruciate ligament ruptures, femur fractures and acetabulum fractures. It is an indicator for the degree of severity of the patients injury [19]. However although our investigation was reversed from knee injuries to correlating injuries of the femu-hip-pelvis complex we were unable to identify this injury often.

DISCHINGER [13] noticed in a US study for accidents occurring in the years 1991 to 1994 that men suffered more frequently from factures of the pelvis and women from factures of the lower extremities. Patella fractures occurred in 2% of the drivers protected by a seat-belt, more frequently with airbags than without. People suffering from knee injuries cause the second highest costs for medical treatment today. For the emergence of knee injuries the impact situation of the vehicle plays an important role. Still, car occupants do not number among the especially risk exposed traffic participants with knee injuries. These occur especially frequently among the so-called “vulnerable road users”. According to our investigation about 36% of the motorcyclists, 25% of the bicyclists and 22% of the pedestrians suffer knee injuries of the degree of severity AIS 1+, if they are victims of a traffic accident, whereas only 10% of the car occupants are thus concerned. The introduction of the safety belt, a continuously optimized safety features equipment in cars, with padding and ‘defusing’ of the dash board resulted in this significant reduction of the risk of knee injuries in a car.

A study carried out by TERESINSKI [25] found in a post mortem investigation at the Department of Forensic Medicine in Dublin, knee joint injuries in 214 out of 357 fatal pedestrian victims of traffic accidents (60%). He pointed out that knee injuries are frequently observed in pedestrian victims of traffic accidents and in his description of mechanisms he showed that the cross-section of tibial and femoral epiphyses bone bruises due to compression and avulsion and the bone bruises in the central tibial and femoral condyles were observed only in victims hit in an upright position. There should be a strong correlation between the side of impact on the extremities in medium sized pedestrians (from the front, back, lateral and medial side) caused by passenger cars and the mechanism of knee injuries (hyperextension, anterior dislocation of the proximal tibial epiphysis in relation to the femoral condyles, valgus and varus flexion). In the cases of very low impacts (e.g. in very tall victims hit by rapidly breaking wedge-shaped cars) or very high impact (e.g. in very short victims hit by trucks) the “reversed” complexes of injuries were found (lever principle).

The high percentage of lower extremity injuries as seen in collisions with cars demands further analysis of this type of crash scenario. The forces induced by the bumpers result in a high bending moment at the level of the knee and the proximal tibia. An alteration in design of automobile bumpers with increased padding for example or with exterior airbags may reduce the frequency and/or severity of these injuries. This allows the assumption that an optimized height design of the bumper and an optimization of the front end of the car can lead to a reduced risk of injury where a knee impact trauma is concerned.

The study showed that the motorcyclists are under risk for knee injury if a frontal direct impact to the knee occurs and based on the resulting relative motion of the human body on the bike a load is transmitted frontally to the patella following in patella fractures. Based on the following movement of the human off the bike a bending rotation mechanism is possible transmitting stress load to the ligaments on one hand. It is also possible that the tibia is forced posterior relative to the femur. The posterior cruciate ligament is usually tight when the knee is in 90 degree flexion and is therefore at high risk for disruption. The conclusions found in the course of this study can be used to improve the current computer simulation of motions and load behavior. They can also supplement the current component tests for the protection of pedestrians concerning kinematics resulting in knee injuries and finally they can also be used to include the requirements for the bicycle impact into such test regulations

However, the influence of air bags on lower extremity injuries, and in particular injuries to the knee, has not been examined effectively in previous field studies since they lacked sufficient number of air bag equipped vehicles in their real world crash dataset. Not only the knee bag or use of restraint devices in the car must be mentioned furthermore there is a need for developing technical features to protect the vulnerable road user.

Pedestrians’ injuries gained attention in road crossing, whereas a large proportion of passengers who were injured inside the car passengers exists. The latter were injured while improperly seated without seat-belt protection. An estimated higher risk of knee injuries was confirmed while using motorcycles and bicycles. This study aimed at achieving an increased understanding and knowledge about the accident pattern in the traffic environment in Hannover.

This study let to some new facts about road traffic-related knee injuries. There is definitely a need to continue our observations in an in-depth study regarding the mechanisms of accidents leading to these injuries. Strategies have to be developed to provide effective prevention. Medical and economical consequences of knee injuries in road traffic show that there is a need to enhance active and passive safety devices in road vehicles.

It can be stated that only 1.2% of the pedestrians involved in road traffic accidents, 0.5% of the bicyclists and 1.6% of motorized two-wheeler drivers were injured at the knee in the course of a collision with a car. This incidence can be called a low risk. It was also found that the risk for knee injuries was significantly lower than 10 or 20 years ago. Knee injuries are not necessarily but in general significantly related to a high impact velocity of the car, they have been observed for speeds lower than 10km/h on the one hand, but 50% occurred at speeds above 35km/h for pedestrians and above 25km/h already for accidents involving bicycles, for motorcycle accidents 50% of the relative speeds exceeded 50km/h.

Advancement in vehicular designs, with specific attention to air-bags, dashboards, and firewalls, needs to be made to reduce the incidence and magnitude of lower extremity trauma in motor vehicle accidents. Seat-belts remain the most effective restraint in the prevention of lower extremity trauma in the motor vehicle.

The study also reveals how important scientific in-depth investigations are und that the depth of information also supplies details of comprehensive injury documentation. A limitation to this study is that the population risk, taking into account time spent in each injury relevant activity is not available. This is shared by most real-world injury investigations.

The aerodynamic shape of current cars compared to older types reduced the incidence and severity of knee injuries. Further modification and optimization of the interior and exterior design could be a proper measurement. Classic described injury mechanisms were rarely identified. It seems that the AIS is still underestimating extremity injuries and their long term results.

References

[1] AAAM: The Abbreviated Injury Scale- 1990 Revision, Update 1998. Des Plaines, IL (1998)

[2] B. ALDMAN, J. KAJZER, O. BUNKETORP: An Experimental Study of a Modified Compliant Bumper. 10th International Technical Conference ESV, 1035-1040 (1985)

[3] H. APPEL, A. KUEHNEL, G. STUERTZ, H. GLOECKNER: Pedestrian Safety Vehicle – Design Elements – Results of In-Depth Accident Analyses and Simulation. 22nd AAAM Conference, 132-153 (1978)

[4] S.J. ASHTON: The Cause and Nature of Head Injuries Sustained by Pedestrians. International Research Committee on the Biokinetics of Impacts 2nd International Conference, 101-113 (1975)

[5] T. ATKINSON, P. ATKINSON: Knee injuries in motor vehicle collisions: a study of the National Accident Sampling System database for the years 1979-1995. Accid Anal Prev 32, 779-786 (2000)

[6] T. ATKINSON, P. ATKINSON: Knee injuries in motor vehicle collisions: a study of the National Accident Sampling System database for the years 1979-1995. Accid Anal Prev 32, 779-786 (2000)

[7] T. ATKINSON, P. ATKINSON: Lower extremity injuries in motor vehicle collisions: a survey of NASS 1997-1999. International Journal of Vehicle Design 32, 173-183 (2003)

[8] B. BRAUTIGAN, L. JOHNSON: The epidemiology of knee dislocations. Clin Sports Med 19, 387-397 (2000)

[9] B. BRAUTIGAN, L. JOHNSON: The epidemiology of knee dislocations. Clin Sports Med 19, 387-397 (2000)

[10] O. BUNKETORP, B. ALDMAN, R. EPPINGER: Experimental Study of a Compliant Bumper System. Ircobi Stapp Conference 287-297 (1983)

[11] C. CAVALLERO, D. CESARI, M. RAMET: Improvement of Pedestrians Safety, Influence of Shape of Passenger Car Front. SAE 830624, 225-237 (1983)

[12] P.C. DISCHINGER, K.M. READ, J.A. KUFERA, T.J. KERNS, C.A. BURCH, N. JAWED, S.M. HO, A.R. BURGESS: Consequences and costs of lower extremity injuries. Annu. Proc. Assoc. Adv Automot. Med 48, 339-353 (2004)

[13] P.C. DISCHINGER, K.M. READ, J.A. KUFERA, T.J. KERNS, C.A. BURCH, N. JAWED, S.M. HO, A.R. BURGESS: Consequences and costs of lower extremity injuries. Annu. Proc. Assoc. Adv Automot. Med 48, 339-353 (2004)

[14] G.J. DUNCAN, R. MEALS: One hundred years of automobile-induced orthopedic injuries. Orthopedics 18, 165-170 (1995)

[15] I. IAKOVAKIS, N. DESSYPRIS, M. DALAMAGA, E. PETRIDOU: A cluster analysis of road traffic-related childhood knee injuries. Child Care Health and Development 29, 297-301 (2003)

[16] M. KRAMER, K. BUROW, A. HEGER: Fracture Mechanism of Lower Legs Under Impact Load. 17th Stapp Car Crash Conference 81-100 (2005)

[17] T. MAKI, J. KAJZER, K. MIZUNO, Y. SEKINE: Comparative analysis of vehicle-bicyclist and vehicle-pedestrian accidents in Japan. Accid Anal Prev 35, 927-940 (2003)

[18] T.R. MILLER, N.M. PINDUS, J.B. DOUGLASS: Medically Related Motor-Vehicle Injury Costs by Body Region and Severity. J Trauma 34, 270-275 (1993)

[19] R. MOSHEIFF, D. SEGAL, R. WOLLSTEIN, S. SAGIV, M. LIEBERGALL: Midshaft femoral fracture, concomitant ipsilateral hip joint injury, and disruption of the knee extensor mechanism: a unique triad of dashboard injury. Am J Orthop 27, 465-473 (1998)

[20] H.B. PRITZ: Comparison of the Dynamic Responses of Anthropomorphic Test Devices and Human Anatomic Specimens in Experimental Pedestrian Impacts. 22nd Stapp Car Crash Conference, 341-357 (1978)

[21] M. RICHTER, C. BECKER, J. SEIFERT, F. GEBHARD, O. PIESKE, M. HOLCH, G. LOB: Prävention von Verletzungen im Alter. Unfallchirurg 105, 1076-1987 (2002)

[22] M. RICHTER, D. OTTE, H.C. PAPE, S. GLUEER, B. KOENEMANN, H. TSCHERNE: Verletzungen von Kindern und Jugendlichen im Straßenverkehr. Unfallchirurg 104, 733-741 (2001)

[23] M. RICHTER, H. THERMANN, H. RHEINBABEN, E. SCHRATT, D. OTTE, H. ZWIPP, H. TSCHERNE: Frakturen der Fußregion bei Pkw-Insassen. Unfallchirurg 102, 429-433 (1999)

[24] T.G. SANDERS, M.A. MEDYNSKI, J.H. FELLER, K.W. LAWHORN: Bone Contusion Patterns of the Knee at MR-Imaging: Footpoint of the Mechanism of Injury. Scientifc Exhibit RG 20, 135-151 (2000)

[25] G. TERESINSKI, R. MADRO: Knee joint injuries as reconstructive factors in car-to-pedestrian accidents. Forensic Science International 124, 74-82 (2001)

[26] J.K. YANG: Mathematical simulation of knee responses associated with leg fracture in car-pedestrian accidents. IjCrash 2 No 3, 259-271 (1997)

[27] E. ZALOSHNJA, T. MILLER, E. ROMANO, R. SPICER: Crash costs by body part injured, fracture involvement, and threat-to-life severity, United States, 2000. Accid Anal Prev 36, 415-427 (2004)

Session: Regulations and Consumer Aspects

C. Pastor

F.A. Berg, P. Rücker, M. Gärtner, M. Groer

K. Okamura, K. Mori, Y. Nishida

C. Pastor
Bundesanstalt für Straßenwesen,
Bergisch Gladbach, Germany

Paired-Comparison Study: Correlation between Euro NCAP Star Ratings and Accident Data from the National German Police Road Accident Statistics

Abstract

Today, Euro NCAP is a well established rating system for passive car safety. The significance of the ratings must however be evaluated by comparison with national accident data. For this purpose accidents with involvement of two passenger cars have been taken from the German National Road Accident Register (record years 1998 to 2004) to evaluate the results of the NCAP frontal impact test configuration.

Injury data from both drivers involved in frontal car to car collisions have been sampled and have been compared, using a "Bradley Terry Model" which is well established in the area of paired comparisons. Confounders – like mass ratio of the cars involved, gender of the driver, etc. – have been accounted for in the statistical model.

Applying the Bradley Terry Model to the national accident data the safety ranking from Euro NCAP has been validated (safety level: 1star <2 star <3 star <4 star). Significant safety differences are found between cars of the 1 and 2 star category as compared to cars of the 3 and 4 star category. The impact of the mass ratio was highly significant and most influential. Changing the mass ratio by an amount of 10% will raise the chance for the driver of the heavier car to get better off by about 18%. The impact of driver gender was again highly significant, showing a nearly 2 times lower injury risk for male drivers. With regard to the NCAP rating drivers of a high rated car are more than 2 times more probable (70% chance) to get off less injured in a frontal collision as compared to the driver of a low rated car.

Introduction

Today, Euro NCAP is a well established rating system for passive car safety. The significance of the ratings must however be evaluated by comparison with accident data. The variety of real world crash events raises the question, whether everyday scenarios can be covered by a small number of crash tests, conducted under artificial circumstances. Recent studies have already shown a positive correlation between the NCAP rating and real world crash performance. However, none of the studies have shown the size of the effect as compared to other effects, generated by confounders like mass difference of the cars in a two car crash or gender of the driver, etc. In addition several models have been used which do not account for the multilevel structure of traffic accidents but just compare the relative performance of cars using accident databases.

Hence, the central objective of my study was (1) to detect any correlation between NCAP rating and real world crash behaviour by means of sound statistical models which account for the multilevel structure of accidents as well as (2) to compare the effect attributed to the NCAP rating with other effects attributed to covariates like mass difference of cars or age and gender of the drivers involved.

The Bradley Terry Model

There is considerable existing work in the statistics literature concerning the repeated ranking of members of a group of individuals. The most fundamental model in this field is generally attributed to BRADLEY and TERRY. The Bradley Terry Model deals with the area of paired comparisons, where ranking takes place between members drawn from a group two at a time. In the model each member is assigned a real-valued positive number η. Thus for a group of m individuals, with $\eta=(\eta_1,....,\eta_i,....\eta_m)^T$, where η_i is associated with individual i, the probability p_{ij} of individual i being superior to individual j is given by

$p_{ij}=\eta_i/(\eta_i+\eta_j)$; $Odds_{ij}=\eta_i/\eta_j$.

The standard model can alternatively be expressed in the logit-linear form

Logit $[p_{ij}]=\lambda_i-\lambda_j$, where $\lambda_i=\log(\lambda_i)$ for all i.

Thus, assuming independence of all contests, the parameters λ_i, λ_j, etc. can be estimated by maximum likelihood standard methods.

To put the model in a crashworthiness context, consider the individuals to be passenger cars, being involved in two car collisions. Here η can be thought of as representing the crashworthiness of car i and p_{ij} as the probability of the passengers of car i getting away less injured than the passengers of car j, in a collision between the two. Clearly this model lends itself to the case of one-on-one collisions (1:1 matching or pair matching).

From a statistical point of view the restriction to two-car accidents (1:1 matching) has the advantage that all observed and unobserved characteristics of the accident itself (time, location, weather conditions, severity etc.) are the same for both accident-involved cars and, therefore, these characteristics cannot account for differences in the injury risk of the two drivers involved in the accident. Consequently, the 'pure' effect of NCAP rating on the probability of car driver injury can be measured more precisely. However, on the other hand, a number of accidents (single car accidents, accident between cars with identical rating or accidents with cars not rated) are ruled out and can not be used in the context of this model.

The Bradley Terry Model has been widely studied and has many generalisations and applications in a broad range of areas. In-depth explanations of which can be found in many sources [DAV, HUN, FIR].

When using the Bradley Terry Model in connection with crashworthiness ratings it is fundamental to choose a reasonable "winner function", a function which decides what car is the 'winner' in a car to car competition – or in other words in a two-car accident. There are several possibilities, e.g. defining a Severity Score S

$$S = f\,(\#\text{fatalities}, \#\text{serious}, \#\text{slight})$$

for each car declaring the car with the lower severity score to be the winner. However, in my study only the injury severity of the driver of each car was used as severity score S, thus the car with the less injured driver won the competition. Having a more sophisticated "winner function" can be beneficial as this can reduce the number of ties, where both parties show the same injury severity score. Clearly those kind of accidents (ties) do not contain any information about the relative crash performance of the two cars involved in the crash.

Data

For purposes of this study a sample of the German police recorded accident register with car to car accidents between 1998 and 2002 was available. These dataset contains NCAP tested vehicles and non-NCPA tested vehicles.

There are 235,047 (out of 981,627) vehicles which could be considered NCAP tested. The classification of car type and model has been done on the basis of the German type- and vehicle-manufacturer code, which distinguishes cars by their motorization, chassis, kind of propulsion, cubic volume to name a few. It was decided that these variables can sufficiently specify a certain car in order to decide whether it is similar to the NCAP tested variant or not.

The sample dataset was supposed to be a 70% sample of the German Official Police Traffic Accident Statistics of car to car collisions where just two cars have been involved in the accident.

Figure 1.1 summarizes the number of accidents with fatal, serious and slight consequences for any car passengers in car to car collisions. The sample dataset contains 53% of all cars where passengers had fatal injuries, 56% of all cars where the driver sustained serious injuries and 57% of all cars with slight injury consequences. If one reduces the sample set to NCAP tested vehicles only, the data contains 9% of all cars with fatal consequences to passengers, 12% of all cars with serious and 14% of all cars with slight injury consequences. Thus it could be estimated that 18% of all fatalities happen in cars which are NCAP tested.

It becomes obvious, that NCAP vehicles are under-represented in the group of fatal and serious

	Fatalities		Serious Inj.		Slight Inj	
	Number	%	Number	%	Number	%
ALL police recorded accident data (1998-2002)	5,327	100	101,265	100	699,700	100
Sample database	2,807	53	56,266	56	401,666	57
Sample database with NCAP tested vehicles only	501	9	11,761	12	97,666	14

Figure 1.1: Sample size of GERDAT and GERDAT_NCAP as compared to the national police data (for accidents involving two cars)

Ctyp	0		1		2		3		4		5		6		7		8	
Atyp	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng
1	1,2	0,2	0,0	0,2	0,2	0,2	0,0	0,2	**17,8**	**9,0**	0,0	0,0	0,0	0,2	3,0	0,4	3,0	1,0
2	0,2	0,0	0,0	0,0	0,0	0,2	0,0	0,0	0,8	0,2	1,2	0,6	0,0	0,0	0,0	0,4	0,0	0,0
3	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,0	0,0	0,0	**15,4**	**3,0**	0,0	0,0	0,0	0,2	0,0	0,0
4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
5	0,0	0,0	0,0	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
6	0,6	0,8	0,2	0,0	0,6	0,6	1,4	1,0	**16,6**	**10,4**	0,0	0,0	0,0	0,2	1,0	0,6	1,2	0,2
7	0,4	0,0	0,4	0,2	0,0	0,0	0,0	0,0	1,8	0,6	0,8	0,0	0,0	0,6	0,6	0,0	0,0	0,2

Figure 1.2: Distribution [%] of combinations of Ctyp (kind of accident) and Atyp (type of accident) for all fatal cases with NCAP tested cars; separated into guilty (g) and not guilty (ng) party (n=501)

Ctyp	0		1		2		3		4		5		6		7		8	
Atyp	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng
1	0,4	0,4	0,3	0,2	0,3	0,4	0,3	0,2	**5,5**	**8,5**	0,1	0,1	0,0	0,0	1,3	0,7	1,3	0,9
2	0,1	0,2	0,1	0,1	0,5	0,9	0,1	0,1	1,6	2,2	3,0	3,9	0,0	0,0	0,0	0,1	0,0	0,0
3	0,1	0,2	0,1	0,1	0,0	0,0	0,0	0,0	0,1	0,2	**13,3**	**14,2**	0,0	0,0	0,0	0,0	0,0	0,0
4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
5	0,1	0,0	0,5	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
6	0,3	1,0	0,4	1,0	2,9	4,5	1,0	1,4	**6,6**	**10,1**	0,1	0,2	0,0	0,0	0,4	0,7	0,4	0,6
7	0,7	0,5	0,5	0,2	0,3	0,1	0,1	0,1	0,6	0,7	0,2	0,2	0,1	0,1	0,2	0,1	0,3	0,1

Figure 1.3: Distribution [%] of combinations of Ctyp (kind of accident) and Atyp (type of accident) for all serious cases with NCAP tested cars; separated into guilty (g) and not guilty (ng) party (n=11,761)

Ctyp	0		1		2		3		4		5		6		7		8	
Atyp	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng
1	0,1	0,3	0,2	0,5	0,2	1,1	0,1	0,2	**1,2**	**3,4**	0,1	0,2	0,0	0,0	0,3	0,4	0,3	0,4
2	0,1	0,2	0,1	0,7	0,6	3,2	0,1	0,2	1,2	2,1	3,0	5,6	0,0	0,0	0,0	0,0	0,0	0,0
3	0,1	0,2	0,1	0,2	0,0	0,1	0,0	0,0	0,1	0,2	**9,1**	**18,6**	0,0	0,0	0,0	0,0	0,0	0,0
4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
5	0,0	0,1	0,5	0,7	0,0	0,2	0,0	0,0	0,0	0,1	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0
6	0,2	0,8	0,6	4,4	*3,1*	*21,3*	0,6	1,6	**1,4**	**3,7**	0,1	0,1	0,0	0,0	0,1	0,4	0,1	0,4
7	0,4	0,7	0,3	0,6	0,1	0,6	0,1	0,1	0,2	0,4	0,2	0,4	0,0	0,0	0,1	0,1	0,1	0,1

Figure 1.4: Distribution [%] of combinations of Ctyp (kind of accident) and Atyp (type of accident) for all serious cases with NCAP tested cars; separated into guilty (g) and not guilty (ng) party (n=97,666)

casualties. Although they make up 24% of the sample dataset, they make just 17% of the fatal cases and 21% of the serious cases [fatal: 1/0,53*0,09=0,17; serious: 1/0,56*0,12=0,21].

Looking in more detail at the structure of the accidents described by “kind” and “type” of accident there are some interesting facts becoming obvious (see Figure 1.2 to 1.4).

Certain combinations of the kind of accident (Ctyp), which describes the entire course of events in an accident, and the type of accident (Atyp), describing the conflict situation, turn out to represent most of the fatal casualties. Details on the exact definitions of CTyp and ATyp can be found elsewhere [STA].

The combinations (Atyp/Ctyp), (1/4), (6/4) do represent front to front crashes, (6/4) being the “classical” example for a front to front collision, whereas in (1/4) one party looses control on its car and wherefore receives more often serious consequences. Both types of accidents are responsible for nearly 54% of all fatal casualties in NCAP tested vehicles and nearly 31% of all serious cases in NCAP tested vehicles.

The combination (3/5) mainly builds up of front to side collisions, having the fatal consequences for the guilty party (Figure 1.2). This is usually the vehicle crossing the street and getting the side impact.

Database	Numbers
NCAP vehicles in the SAMPLE DATABASE	235,047
Accidents with at least one NCAP vehicle	212,672
“Front-Front“ accidents with at least one NCAP vehicle	17,962
“Front-Front“ accidents with both cars NCAP-tested	1,963
“Front-Front“ + “NCAP-NCAP“ + accident with at least one person sev. or fatally inj.	495

Figure 2.1: Relevant case numbers in the database

Looking at the slight injury cases (Figure 1.4) the combination (6/2) becomes obvious. These are rear end collisions with a stopping vehicle and the slightly injured person is most often the person in the stopping vehicle.

With regard to the matched pairs design of the study front to front collisions have been considered to produce the most ideal “pair” for two car collisions whereas both cars sustain more or less the same crash severity. This is most truly given in a front to front accident configuration. As described these accidents can be identified by proper combinations of kind and type of accident, here Atyp/Ctyp combinations (1/4) and (6/4). Comparison with the NCAP star rating was thereby restricted to comparisons with the frontal star rating only.

For this study it was furthermore decided that accidents with fatal and serious outcomes should be most meaningful with regard to the NCAP star rating. Here only the injury status of the drivers have been taken into account.

However, the numbers of available accident cases decreases rapidly when the data is restricted to this interesting group of accidents. This is quite natural taking into account the great number of low severity accidents which are excluded from the analysis. Furthermore NCAP tested cars do not often collide with another NCAP tested car, but more often with other not NCAP tested cars, which can be seen by comparing row 1 and 2 of Figure 2.1.

Within the remaining 495 car to car accidents there have been 64 fatalities, 771 severely injured and 453 slightly injured persons.

Data Analysis

The study focuses on frontal car to car collisions of NCAP tested cars and compares the real world performance to the frontal offset test results of the NCAP assessment. The official frontal rating is calculated using the crash dummy readings of both frontal passengers. This rating has been recalculated to assess merely the driver readings, thus giving a frontal rating for assessing the drivers risk of getting injured. This procedure was carried out by the Monash University in the course of the SARAC2 project. Using this kind of assessment complies with the “winner function” as described in the paragraph, describing the Bradley Terry Model.

Winner	Loser	Frequency	Reduced Frequency
1-STAR	1-STAR	14	-
2-STAR	1-STAR	22	22
3-STAR	1-STAR	28	28
4-STAR	1-STAR	6	6
1-STAR	2-STAR	16	16
2-STAR	2-STAR	48	-
3-STAR	2-STAR	62	62
4-STAR	2-STAR	12	12
1-STAR	3-STAR	12	12
2-STAR	3-STAR	37	37
3-STAR	3-STAR	36	-
4-STAR	3-STAR	10	10
1-STAR	4-STAR	2	2
2-STAR	4-STAR	4	4
3-STAR	4-STAR	9	9
4-STAR	4-STAR	3	-
SUM		321	220

Figure 3.1: Winner-Loser-Frequency Matrix of frontal car to car collisions of NCAP tested cars

Before starting the analysis the only 0-STAR car in the database, a Chrysler Voyager, was decided to be taken out. Setting up the data into a winner/loser shown matrix produces the result in Figure 3.1.

Figure 3.1 contains information on 321 car to car frontal collisions. This means that there have been 174 ties out of 495 accidents, where the injury status of both colliding cars have been identical and which have for this reason been of no value for the analysis. However, more cases of the table do not contain valuable information for the model, because winner and loser are of the same category. Referring to the second frequency column in Figure 3.1, the number of valuable accidents reduces to 220. Looking at the matrix the NCAP star rating seems to make sense, since higher rated cars do more often win against lower rated cars and vice versa.

	λ_i Estimate	Std.Error	Signif
1-STAR	0,000	0,000	-
2-STAR	0,306	0,247	0,2145
3-STAR	0,855	0,249	0,0006
4-STAR	1,133	0,378	0,0027
Null deviance: 445 on 321 degrees of freedom Residual deviance: 425 on 318 degrees of freedom AIC: 431			

Figure 3.2: Crashworthiness estimation by using a simple Bradley Terry Model

	λ_i Estimate	Std.Error	Signif
1-STAR	0,000	0,000	-
2-STAR	0,439	0,274	0,1086
3-STAR	0,714	0,274	0,0092
4-STAR	0,900	0,412	0,0291
MR	1,692	0,312	5,9e-08
FEMALE	-0,590	0,191	0,0021
Null deviance: 442 on 319 degrees of freedom Residual deviance: 362 on 314 degrees of freedom AIC: 372			

Figure 3.3: Crash-worthiness estimation by using a Bradley Terry Model with covariates adjustment

Fitting the data to a Bradley Terry Model produces the result, shown in Figure 3.2. Again, there is a clear tendency for better rated cars being more crashworthy than lower rated cars. The standard deviation does not allow for a separation of each class category. Thus it is possible to distinguish between a 1-star and a 3-star car, and also between a 1-star and a 4-star car. All other confidence intervals overlap on a 5% significance level.

By extending the model one can include confounding variables. Mass ratio (MR) defined by

MR=max.weight(winner)/max.weight(loser)

and gender of the driver have shown to be of significance.

Figure 3.3 shows the results. The mass ratio is significantly marked to play an important role in front to front car collisions.

Results

The main results of the study can be summarized as follows:

(1) After adjusting for confounding factors there remains a significant safety difference between cars of the 1- and 2- star category and cars of the 3- and 4- star cars, thus the NCAP star rating seems to be reflected by real world accidents.

(2) The mass ratio of the cars involved in a frontal car to car accident is the most powerful covariate. A 10% change in mass ratio results in a 20% increase in probability to get better off in an accident, or in other words the odds to get better off change from 50/50 to 60/40 for the driver of an equally rated but heavier car.

(3) There is a gender effect. Female drivers show an almost 2 times higher injury risk. The odds change from a 50/50 chance to get better off to a 35/65 chance for a female driver of an equally rated car of similar weight.

(4) The NCAP rating can have at a maximum chance the odds from 50/50 to 30/70, thus the driver of the lower rated car is 2 times more probable to get more injured in a crash.

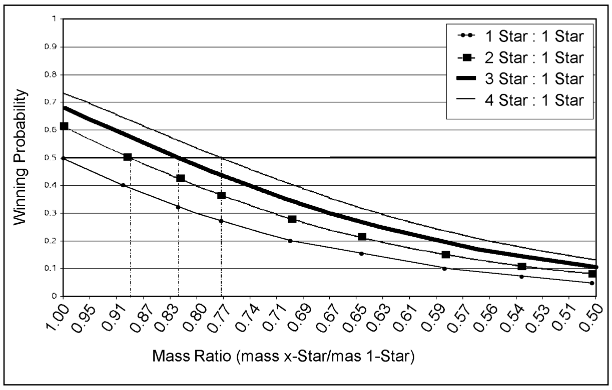


Figure 4.1: Comparison of star rating and mass ratio influence in frontal car to car accidents

The influence of the star rating as compared to the impact of mass ratio is depicted in Figure 4.1. The baseline car for all curves is an impact with a 1-star rated car.

Accidents between two 1 star rated cars with mass ratio 1 show a winning probability of 50% which is trivial. A collision between a 2-star and a 1-star rated car of equal weight shows a winning probability for the 2-star car of 62% and so on. It could be seen that the advantage of a 4-star car as compared to a 1-star car is compensated when the mass ratio reaches a value of 0,77; thus a 2,000kg 1-star car hitting a 1,500kg star 4-star car both will have a 50% probability of getting better off. Similar comparisons could be done with the other covariate which was the gender of the driver. The advantage of driving a 4-star car is thus compensated by the fact of a female driver when hitting a 1-star car with a male driver.

In further analysis it would be desirable to include further covariates like age of driver which has not been considered here. The special dataset of this study did not contain enough information for this purpose. It would furthermore of interest to extend the Bradley Terry Model to make more use of ties (accidents between cars with the same injury severity score).

Acknowledgements

This study was sponsored by the European Commission and carried out in context of the SARAC2 project. The author is especially graceful to the Monash University Accident Research Center (Prof. Max Cameron, Amanda Delaney) for providing data of the recalculated NCAP scores based on the driver dummy readings only.

References

DAV: H.A. DAVID: The Method of Paired Comparisons, 2nd edition, Oxford University Press, New York (1988)

FIR: D. FIRTH: Bradley Terry Models, Journal of Statistical Software, 12, 1-12 (2005)

HUN: D.R. Hunter: MM algorithms for generalized Bradley Terry Models, Annals of Statistics, 32, 384-406 (2004)

STA: Verkehrsunfälle – Fachserie 8, Reihe 7, download via http://www-ec.destatis.de/

F.A. Berg, P. Rücker, M. Gärtner, M. Groer
DEKRA Automobil GmbH, Accident Research & Crash Test Center, Stuttgart, Germany

Crash Tests to Assess the Secondary Safety of Cars in the so-called “8,000-Euro Class”

Abstract

The price of a new car increased almost every year for a long period. In recent years however, the budget available to most people for purchasing a car either did not grow or became even smaller. Therefore it was in the interest of some OEMs to offer economical car models in the so-called “8,000-Euro class”. Here an important question arose regarding the safety of these vehicles. There is no question that the very high safety level of cars reached in Europe during the last decades should not be sacrificed as a consequence of smaller budgets. Customers with sense of responsibility have the right to be properly informed about the balance between safety and price so that they can make a deliberate decision when buying either a new or a used car.

Against this background, the German magazine “AutoBILD” commissioned DEKRA to conduct full-scale frontal crash tests with a view to publishing the results. These tests have been carried out in accordance with the corresponding Euro NCAP crash test requirements and performance criteria. The tested vehicles were two new Logans produced by the manufacturer Dacia, two used cars of the type VW Golf IV (registration date 2000) and one new VW Fox.

This paper describes the safety features of the vehicles and the results of the five crash tests to demonstrate state-of-the-art safety levels and what levels may be expected from vehicles in the “8,000-Euro class”.

Looking at real-world crashes it is of interest to think about future trends in a more detailed manner. Therefore it will be more and more necessary to supplement the federal statistics with more detailed in-depth information about the consequences of accidents and the safety performance of crashed vehicles.

Notation

resp.	respectively
v	velocity [m/s;km/h]
a	acceleration [m/s^2]
M	momentum [Nm]
HIC	Head Injury Criterion [-]

Introduction

According to the “Allgemeiner Deutscher Automobil Club (ADAC)” the expenses for purchase and maintenance of a car in Germany increased by an average of 37.7% from 1991 to 2001, Figure 1. This equals an annual average increase of 3.0%. In contrast, the cost of living expenses have increased by 27.3%, which represents an annual increase of 2.2% over the same period [1]. The main cost factor there has been the increases in fuel prices. In the year 2002 these were 54.9% above the prices in 1991.The purchase price of a car rose in the same period by 18.3% and consequently the increase has been less than that of the increase in the cost of living. However, in the face of a general shortness of money and the high level of retail prices for new cars it is very desirable to save money here.

Against this background some car manufacturers have set themselves the goal to offer attractive new cars for the German market priced significantly below 10,000 Euros. In the meantime this class has become known as the 8,000-Euro class. The pioneer was Renault. In June 2005 they brought out the Dacia Logan which is assembled in Romania and offered it to the German, French and Spanish market. This car offered (almost) the same compartment and trunk dimensions as the so-called Golf class at a significantly lower price. The Dacia

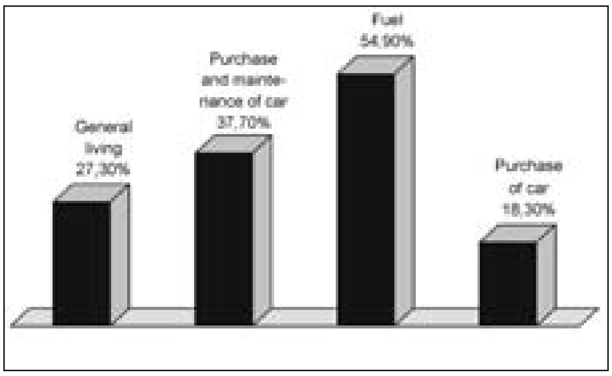


Figure 1: Pattern of cost growth in Germany

Logan is based on the same platform as the Nissan Micra and the Renault Modus. The launch of the Dacia Logan was announced in over 30 countries at the end of 2005. In Germany the list price ranges from 7,200 to 8,200 Euros without any extras. Actually the primary price was targeted to be 5,000 Euros as the “Spiegel” magazine reported in June 2005 [2].

Of course ambitions to offer new cars for little money are appreciated by the consumers. But at the same time the preservation of the high level of vehicle safety available nowadays has to be considered, too. This high level has contributed to a continuous decrease in the numbers of severely and fatally injured people in Germany from the 1970s until today. In 1970 there had been a sad negative record with 21,332 fatally injured road users in Germany. After that, it was possible to reduce this number to 5,482 by the great efforts of all parties. According to estimates made by the Federal Statistical Office this number is still decreasing – and roughly down to 5,400 [3] for 2005. Compared to 1970 this would mean a decline of 75% although the national stock of vehicles increased almost three-fold.

In countries which have not yet reached such a high level of vehicle safety it could be appropriate to set some lower requirements for vehicles. In those countries the vehicles are mostly very old, badly maintained and correspondingly unsafe. In countries like e.g. Germany no cutbacks in the requirements of safety can be tolerated if we do not want to put at risk the positive trend of fewer seriously and fatally injured. In this context also the goals in the White Paper of the European Commission [4] and the European Road Safety Charter [5] have to be taken into account. According to these the number of fatally injured in the EU should be halved by 2010 when compared with 2001. DEKRA is one of the first signatories of the European Road Safety Charter which supports the efforts to achieve this goal on a sustainable basis. In Germany, the subject safety is of much consideration also for low-price cars. The standard equipment of the vehicles includes ABS as well as driver and passenger airbag [6]. However the goals involving crash safety seem to be not always priority number one. The official rating at Euro NCAP for the Dacia Logan is 3 out of 5 possible stars. Current cars of all classes gain 4 to 5 stars [7].

With this background it is of interest to investigate the safety of such vehicles and to publish the results also for the general public. The informed customer can include criteria of vehicle safety on the basis of objective information in his decision whether to buy or not. The German magazine “AutoBILD” picked up this subject first and extensively tested the Dacia Logan. To investigate secondary safety, crash tests have been commissioned at the DEKRA Crash Test Center in Neumünster. These tests were published in April 2005 [8]. A 5 year old, well preserved VW Golf IV was also used to directly provide a comparison with the passive safety of the Dacia Logan. Such a car could also be purchased for a price of 8,000 Euros. The official rating within Euro NCAP for a 1998 VW Golf IV is 4 stars [7].

Additionally another test has been made with a VW Fox which was published in June 2005 [9]. This vehicle is actually a little smaller than the Logan or the Golf but at 9,000 Euro also qualifying for the “under 10,000-Euro class”.

In the following the tests and their results are presented and discussed. In contrast to the publications of “AutoBILD” this will be a mainly technical contribution in which further test results and details will be presented and discussed. Additionally the official Euro NCAP crash test with the Dacia Logan will be included [10].

Crash Tests Conducted with Dacia Logan and VW Golf IV

Task and test configuration

The central task for DEKRA has been the analysis of the safety for the driver and passenger in the Dacia Logan and in the VW Golf IV when involved in the frontal crash according to Euro NCAP. The corresponding article in the magazine “AutoBILD” asked if a new Dacia Logan offers the same passive safety as a used VW Golf IV. Safety relevant differences in the vehicle behaviour and its components should be identified and explained. Some possible variations have also been taken into account during planning of the tests. In addition to the possible technical variations, which are actually marginal, during the execution of such tests further results were obtained possibly due to the influence of production variations in new cars as well as to the condition of the used vehicle. Therefore two

Logans and two Golfs were tested using the same test parameters.

The chosen test configuration complied with the requirements as specified by Euro NCAP – i.e. a 40% offset frontal crash at 64km/h against a barrier, Figure 2. A deformable barrier face is mounted on the rigid barrier at the impact area which deforms in a specified manner under the influence of a force. This impact constellation and the deformation element are also defined in the regulation ECE-R 94 which is standard for vehicle homologation. However, the impact speed used is not 56km/h but 64km/h. According to the philosophy of Euro NCAP this points out differences in the crash performance of the tested vehicles because the relevant test for homologation has to be passed with a good result by all cars.

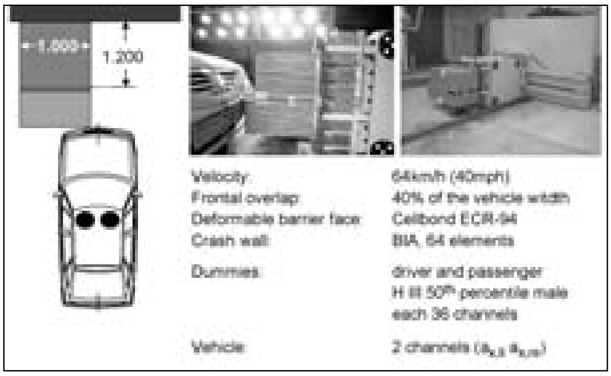


Figure 2: Test configuration

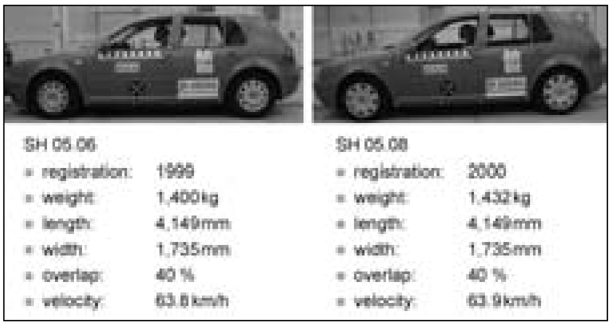


Figure 3: Test vehicles: used VW Golfs IV

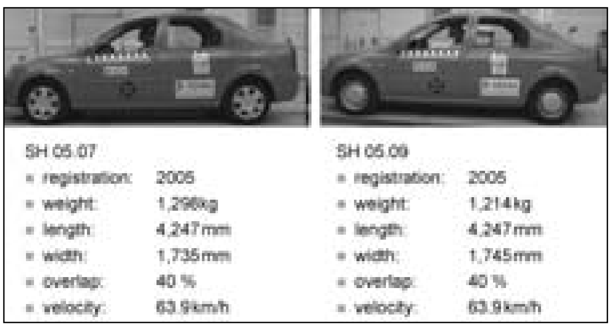


Figure 4: Test vehicles: new Dacia Logans

In addition to the standard test a force-measuring crash wall (manufacturer BIA) was mounted which monitored the magnitude and the sequence of the reaction forces at the impact of the vehicles. Instead of a real driver and passenger anthropometric test devices (dummies) type hybrid III 50th percentile male were used. Both dummies were equipped with 36 channels to measure biomechanical loads. Included are accelerations in the head, chest and pelvis in each three orthogonal directions, the intrusion into the chest as well as further mechanical loads in the neck, femurs, knees and tibia. A uniaxial acceleration sensor was used to measure the deceleration of the vehicle on each side of the vehicle's B-pillar/door sill transition. Each measurement value was recorded with built-in crash-resistant data acquisition units. After the test this data was transferred to an external PC.

Test vehicles

VW Golf IV

Test numbers are used to distinct the tests and the results. For the tests SH 05.06 and SH 05.08 two VW Golf IV were used, Figure 3. The vehicles were licensed in 1999 and 2000 respectively and therefore about 5 years old at the time of the tests. The length of the cars was 4,149mm and the width 1,735mm. The weights including dummies and measurement equipment were 1,400 and 1,423kg resp. The lighter car had been equipped with rims made of aluminium, the heavier one with steel rims. The measured velocities at impact were 63.8 and 63.9km/h resp. The Golf IV is equipped with 3-point seat-belts for driver and passenger. In addition these belt systems have a belt-force limiter. The safety belts are supposed to support the airbags to restrain driver and passenger.

Dacia Logan

Two new Dacia Logans (registration date 2005) were used for the tests SH 05.07 and SH 05.09, Figure 4. The length of the vehicles was 4,247mm and the width 1,735mm. The test weights were 1,214 and 1,298kg resp. The heavier car had been equipped with air conditioning and a bigger rim-wheel combination. Both vehicles impacted at 63.9km/h. The Logan is equipped with 3-point seat-belts for driver and passenger without a belt-force limiter. Frontal airbags are also part of the restraint system.

Impact behaviour

Vehicle structure

All four test vehicles showed a generally similar behaviour by the structures during impact. A detailed inspection showed that the deformation at the Golf appeared a little more harmonic and steady. No differences could be recognized with the two almost identical sequences of the measured forces at the crash wall. However the deceleration of the Golfs took a little longer than the deceleration of the Logans and the peak values of the Golf were lower than the respective values of the Logan. The survival space for the occupants remained adequate. The A-pillars suffered only marginal distortion at the impact side. The displacement of the A-pillars was measured 100mm beneath the window aperture (top) and 100mm above the sill (bottom). The displacement for the Logans was between 7mm at the top and 29 and 30mm resp. at the bottom. For the Golfs it was between 7 and 8mm resp. at the top and 43 and 46mm resp. at the bottom (see Table 1).

The rearward vertical displacement of the upper steering column was 2 and 23mm resp. for the Logans and 27 and 39mm resp. for the Golfs. The displacement at the lower steering column was 12 and 14mm resp. for the Logans and 52 and 65mm resp. for the Golfs.

		VW Golf		Dacia Logan	
		SH 05.06	SH 05.08	SH 05.07	SH 05.09
Door opening forces [kN]					
Driver door	opening	242	137	**blocked**	**blocked**
	45°	641	631	458	171
passenger door	opening	76	75	33	21
	45°	55	45	30	24
Door left backseat	opening	36	52	42	25
	45°	53	56	48	33
Door right backseat	opening	70	56	24	26
	45°	75	50	36	28
Displacements [mm]					
Upper A-pillar		8	7	7	7
Lower A-pillar		46	43	29	30
Gas pedal		36	83	9	14
Brake pedal		80	87	54	21
Clutch pedal		135	129	**222**	170
Upper steering column		27	39	2	23
Lower steering column		65	43	14	12

Table 1: Door opening forces and vehicle distortions

Further measurements were made. The rearward displacement of the pedals for the Logan was: brake 21/54mm, clutch 170/222mm, throttle 14/9mm. For the Golfs: brake 87/80mm, clutch 129/135mm, throttle 83/36mm. The pedals released mechanically because of the impact loads. This technique is nowadays common and reduces the bruise loads on the feet and lower extremities. The Logan did not have such a mechanism.

The doors on the passenger side of all four vehicles could be opened using normal hand force as well as the back doors on the driver’s side. But there was a significant difference when trying to open the driver’s doors. While the doors of the Golfs could be opened with moderate hand force (242kN/137kN), the doors of the Logan had to be opened using a crowbar. The reason for this was clamping of the lock mechanism of the pin-type lock. Unlike the Logan the Golf is equipped with the bracket-type lock commonly used today which prevents such clamping occurring.

Another positive effect observed at all tests has been that no door opened during impact. This is required according to technical standards to prevent passengers from being thrown out of the car. It is furthermore required that at least one door per seat row can be opened without using any tools. As one door could be opened after the test with the Logan this requirement was fulfilled, but a door which can not be opened easily after a crash complicates the care and rescue of injured people – in this case especially for the driver.

Restraint systems

The airbags in the Golfs worked in a normal manner at both tests. This is shown by a firm inflation of the airbag while the passengers are still moving forward relative to the car due to their inertia. In this early phase the passengers are already restrained by the belts. To lower the peak loads for the upper body regions belt-force limiters are activated at a certain trigger force. Such a limitation of the restraint force is common for today’s seat-belts in combination with airbags. That is because the fully deployed airbag can protect the head and upper body and therefore support the restraint efficiency of the belt. In the further sequence the airbag is further compressed by the passengers which are still moving. At this point, airbag gases escape through exhaust vents. During the design of a new vehicle the restraint systems are accurately coordinated to achieve best results which means passenger loads are kept below the biomechanical limits and there is no steering wheel contact with the body or the head. The same applies to the passenger side.

At both tests with the Logan, a behaviour was observed which was classified as unusual. The airbag gases escaped very early. At this early point the airbag could not really support the seat-belts. Significant interaction of the airbag and the passenger could be seen fairly late and during a phase in which the airbag is already droopy because of the escaped gases. Therefore the seat -belts basically restrain the passengers with the result that the measured belt forces are higher for the Logans than for the Golfs.

No bottoming out of the airbags could be observed for either the Golf or the Logan.

Dummy loads

As described before, the survival space for the Golf as well as for the Logan remained almost intact. This adequately complies with an essential part of the basic principle of secondary safety while the measured dummy loads determine the vehicle's safety performance. Firstly, consideration is given to some common used test results of the dummies. Afterwards the dummy loads especially of interest for Euro NCAP will be analysed.

Common used load data

Driver

The technical regulations specify the Head Injury Criterion HIC as well as the highest resulting head acceleration during a time interval of 3ms (a_{3ms}). The HIC is a nondimensional value with a limit of 1,000. The resulting head acceleration has the limit a_{3ms}=80g. If these values are exceeded irreversible injury of the brain and the skull are very likely. The values for the Golf (HIC=358 and 393 resp. and a_{3ms}=45g and 47g resp.) are far below the biomechanical limits, Table 2. This has been a trend-setting feature of vehicles of this generation. Mandatory requirements for these good test results consist of accurately coordinated restraint systems like the safety belt with belt-force limiter and airbag. With a HIC of 943 and 855 resp. and a_{3ms}=79g and 67g resp. the head-load values for the Logan are very high and very close to their limits. This indicates a correspondingly higher risk of injury.

Driver Loads	VW Golf		Dacia Logan	
	SH 05.06	SH 05.08	SH 05.07	SH 05.09
Head HIC	358	393	943	855
Head a_{3ms}	45.15g	46.87g	78.49g	67.34g
Neck M_Y	33.15Nm	29.76Nm	9Nm	22.7Nm
Chest deflection	26.72mm	24.42mm	27.72mm	26.64mm
Chest a_{3ms}	41.8g	38.05g	41.8g	48.46g
Pelvis a_{3ms}	40.6g	39.21g	40.6g	51.08g
Upper femur F_z right	1.94kN	1.75kN	1.94kN	1.84kN
Upper femur F_z left	1.68kN	1.38kN	1.68kN	1.25kN

Table 2: Driver loads

The vertical neck momentum (tension/extension) is used to rate the neck stresses and strains. For the Golfs the measured values were M_y=33Nm and 30Nm resp. and for the Logans M_y=9Nm and 23Nm resp. The relevant limit is 57Nm which is significantly higher than the measured values. Important test results by which to assess the chest loads are the resulting chest acceleration a3ms and the geometrical deflection of the chest. The relevant limits are a_{3ms}=60g and s=50mm resp. The test results for the Golfs were a_{3ms}=42g and 38g resp. and s=27mm and 24mm resp., and for the Logan a_{3ms}=51g and 49g resp. and s=31mm and 27mm resp. These values are far below the relevant limits. For the pelvis area the a_{3ms}-value is used, too. Here the limit is 60g. With results of a_{3ms}=41g and 39g resp. for the Golfs and a_{3ms}=53g and 51g resp. for the Logans these values are not critical. Finally the maximal compressive force of the femur will be addressed. The usual limits are 10kN although some literature mentions 8kN. Both the Golfs (left femur: 1.81kN and 1.75kN resp. and right femur: 2.16kN and 2.25kN resp.) and the Logans (left femur: 1.27kN and 0.97kN resp. and right femur: 1.4kN and 1.14kN resp.) are on the same level and far below the limits.

Overall, the reported values show, that the head of the driver of the Logan was exposed to significantly high loads. This means there would be a high risk of injuries of the head. For other body regions the differences between the Logans and the Golfs are not significant and always below the biomechanical limits.

Passenger

A high level of stresses and strains can be observed when looking at the test results for the head of the Logan's passenger. In both tests the limit for the HIC has been exceeded (HIC=1,197 and 1,016 resp.). The limit for the resulting acceleration of 80g has been exceeded once (a_{3ms}=83g) and the other time almost (a_{3ms}=75g),. The corresponding values for the Golfs (HIC=270 and 172 resp. and a_{3ms}=40g and 32g resp.) are far below those of the Logans. The other body regions of the passenger have also been measured by reference to the load variables already stated. Those are more or less on the same level for both vehicles and below the biomechanical limits.

Passenger Loads	VW Golf		Dacia Logan	
	SH 05.06	SH 05.08	SH 05.07	SH 05.09
Head HIC	270	172	1197	1016
Head a_{3ms}	39.67g	32.26g	82.53g	75.16g
Neck M_Y	21.22Nm	27.43Nm	28Nm	33Nm
Chest deflection	31.98mm	31.24mm	38.47mm	37.56mm
Chest a_{3ms}	33.5g	30.31g	41.71g	41.01g
Pelvis a_{3ms}	37.51g	37.33g	52.52g	46.69g
Upper femur F_z right	1.36kN	1.49kN	0.99kN	1.21kN
Upper femur F_z left	2.37kN	1.97kN	1.16kN	1.4kN

Table 3: Passenger loads

Rating according to Euro NCAP

Additionally to the already mentioned test results the dummies yielded further measurements for the knee and tibia. All of the collected data of summarized to calculate and display the body-related injury risk according to Euro NCAP. Manikins are used to provide easy and clear information to the customers. The injury risks for the head, chest, pelvis, femur, tibia and feet are presented visually by using different segments. Additionally, the feet of the driver show the effects

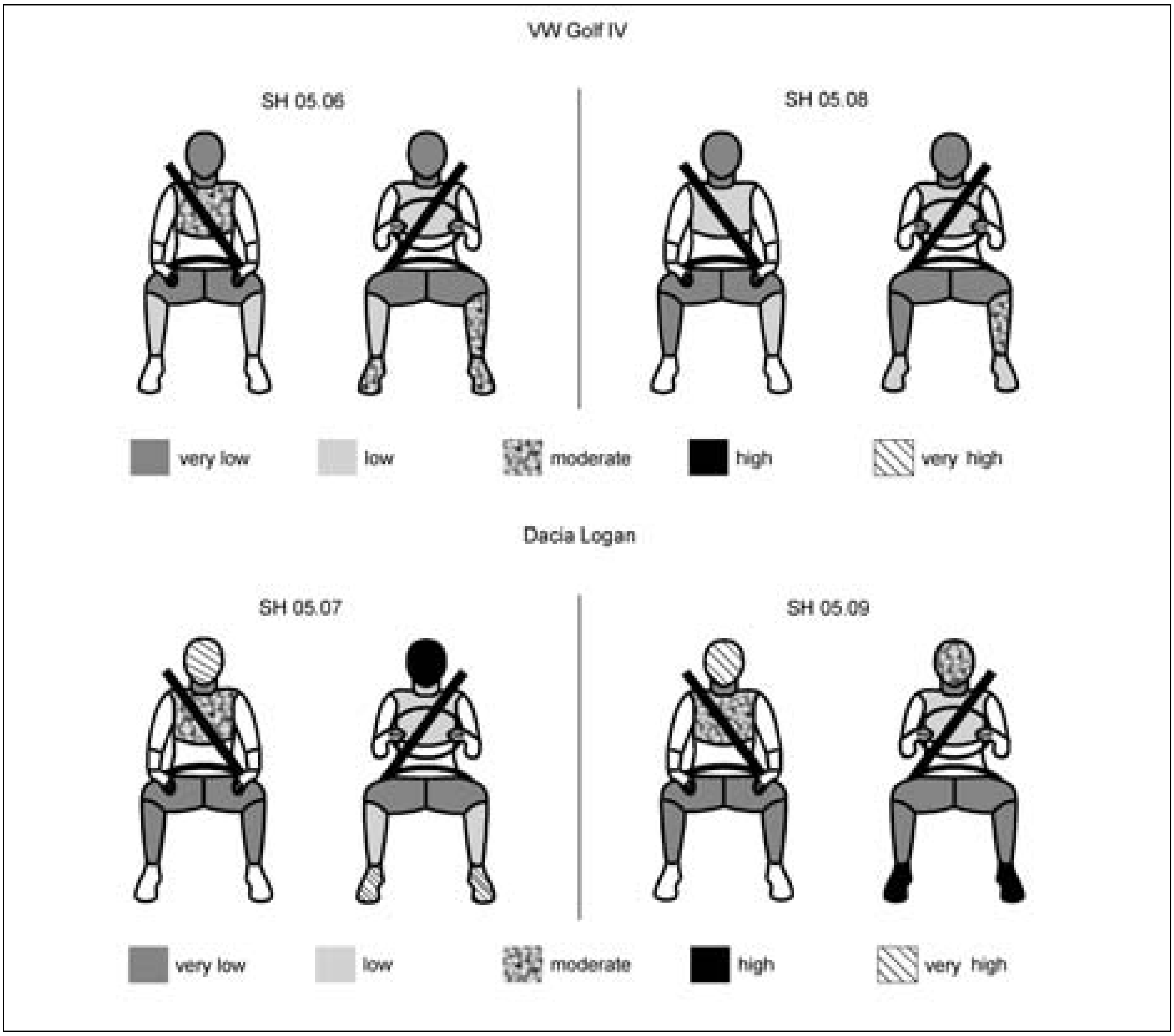


Figure 5: Driver and passenger injury risks as results of the crash tests conducted with Dacia Logan and VW Golf IV

of pedal intrusions. The classification is made by a mathematical algorithm using the dummy measurements as described in the official Euro NCAP protocol [11]. This calculation will be explained in detail considering the head as example. Furthermore the score generated from dummy data may be modified where the protection for different sized occupants or occupants in different seating positions, or when involved in accidents of slightly different severity, can be expected to be less effective than that indicated by the dummy readings or deformation data alone. In any single body region, the score may be reduced by a maximum of up to two points. No modifier has been used by DEKRA in these calculations.

The different segments of the manikins reflect the injury risks, see Figure 5. According to Euro NCAP the loads for the femur and knee were consistently low. The injury risk for the tibia were rated from very low to moderate and for the chest from low to moderate. Also some variances for the same type of car can be seen because of slight differences in the dummy loads. This can be seen particularly clearly if a value is located between two risk groups, e.g. between a low and a moderate risk of injury. A low to moderate injury risk has been assessed for the feet of the driver in the Golf. For the Logan it was rated moderate to high.

Singularity of the head rating

The described high risk of injury for the driver and passenger of the Logan is shown by the different segments of the Euro NCAP manikin. While the Golf was rated with dark grey heads for very low injury, the Logan was assigned with different heads which mean a high or even a very high risk of injury for the head. During the analysis of the test results a discussion came up because the DEKRA test results for the head differed from the official Euro NCAP ones [10]. In this context the Euro NCAP algorithm to calculate the results has to be considered.

Each body region (head and neck, chest, pelvis, femur and knee, tibia and feet) can be awarded a maximum of 4 points. The requirement is that the load of each body region is below or equal the so-called "higher performance limit". The higher performance limit refers to the car not to the occupants. The corresponding risk of injury is very low and displayed by a dark grey body region. The worst rating is 0 points and awarded if one dummy measurement of the body region is equal or over the "lower performance limit". The corresponding risk of injury is very high. Within these two performance limits a "sliding scale" relates the measured value and the awarded points. Within the 0 to 4 achievable points there are further fragmentations which separate the injury risk into low, moderate and high. If one or more loads on one body region result in a rating lower than 4 the worst rating is used for the total result and for the different segments of this body region of the manikin.

To rate the injury risk for the head the resulting acceleration a3ms and the HIC are used. The lower performance limits are HIC=1,000 and a_{3ms}=88g, the higher performance limits are HIC=650 and a_{3ms}=72g. For the Golfs all measured values were lower than the higher performance limit and classified as very low. This can be seen from the dark grey heads for both driver and passenger. The measured loads for the driver dummy of the Logan were HIC=943 and 855 resp. and a_{3ms}=78.49g and 67.34g resp.. These values are slightly lower than the lower performance limit of HIC=1,000 and a_{3ms}=88g but inside the sliding scale. Taking the worst rating these values result in amoderate risk of injury and ahigh risk of injury respectively. For the head of the passenger dummy the measured values were HIC=1,197 and 1,016 resp. and a_{3ms}=82.53g and 75.16g resp.. In both tests the lower performance limit for the HIC of 1,000 was exceeded. This means a high risk of injury for the head. As mentioned above, the risks of injury to the head revealed by the tests have been published to a partial extent in the magazine "AutoBILD". In the meantime the official result of Euro NCAP has also been released. In this the head of the driver and passenger of the Logan has been rated with a very low risk of injury which is reflected by a dark grey head for the manikin [10]. This rating results from a special condition in the Euro NCAP protocol which requires a hard contact with the head to actually rate the risk of injury to the head as high. This hard contact is recognized if the peak value of the resulting acceleration of the head is over 80g. If this is not the case the risk of injury for the head is assessed as "very low" – irrespective of the HIC.

Under this special condition the head injury risk would have been rated high (red) only once –

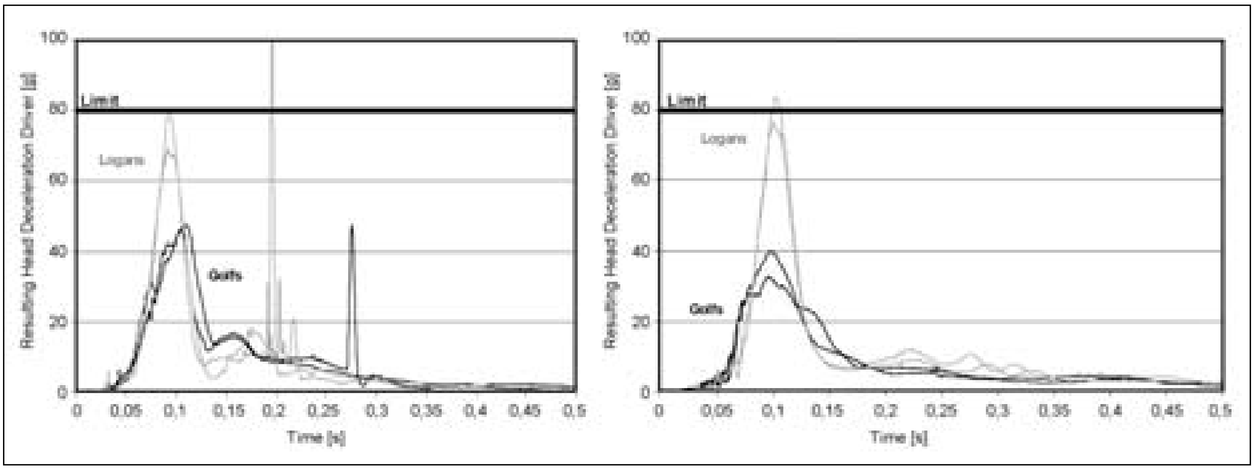


Figure 6: Head decelerations for driver and passenger for all tests conducted with Dacia Logan and VW Golf IV

namely for the passenger of test SH 05.07 (a_{3ms}=82.53g/HIC=1,197). The passenger in the second test with a peak acceleration of a max=76.37g which is below 80g would have received a dark grey head despite an HIC of 1,016 and a_{3ms}=75.16g,. In the face of these high values relative to the biomechanical limits as well as the higher values for the Dacia Logans when compared to the Golfs this special condition was not applied by DEKRA for the rating results published by Auto BILD and the HIC was used to rate the passenger. This resulted in a very high head rating for the second test, too.

The measured maximum values of the resulting head acceleration of the Logan driver were a_{max}=79.97g for test SH 05.07 (HIC=943/ a_{3ms}=78.49g) and amax=79.1 g (HIC 855/a_{3ms} =67.34g) for test SH 05.09. If the special condition had been applied the rating would have been a very low risk of injury. Regarding the test SH 05.07 the small gap of merely 0.03 g would have been decisive for this unrealistic rating. Here too, the special condition was not appplied by DEKRA and the rating was made by using the HIC value. This resulted in a high risk of injury for test SH 05.07 and a moderate risk of injury for test SH 05.09.

During the discussion this approach was considered to provide the most consistent option within the limits of the rating possibilities representing the real risks of injury to the head. This applies also to the absolute value of the loads and on the other hand to the direct comparison with the low values for the Golf. The test results for the Logan represent a marginal case which should be considered in the further development of the official Euro NCAP-protocol.

Crash Test Conducted with VW Fox

Finally, consideration of the results of a frontal test involving a new VW Fox confirms the level of secondary safety which can be already achieved with vehicles in the lower compact class. The Fox is equipped with a seat-belt system with seat-belt pretensioner and seat-belt-force limiter both for both driver and passenger. In a very early phase of the crash the seat-belt pre-tensioner reduces the belt slack. Additionally the Fox is equipped with an airbag for driver and passenger.

The test vehicle weighed 1.238kg. Its length was 3.828m and width 1.660m. In accordance with Euro NCAP the offset was 40 % and the test velocity 63.9km/h. A harmonic deformation of the vehicle crumple zone could be observed during the crash. The passenger cell remained almost intact and the survival space for the occupants remained fully intact. At the driver's side the A-pillar distorted to an insignificant degree. The rating according to Euro NCAP was carried out by DEKRA without using modifiers. The loads on the passenger were consistently very low (all body parts dark grey). For the driver all body parts apart from the chest and the left tibia have been rated a very low risk of injury (dark grey). The chest and tibia have been rated a low injury risk, see Figure 7.

With these results the VW Fox meets the level of the current VW Golf V. The Golf V was rated 2004 with the maximum result of 5 stars [7].

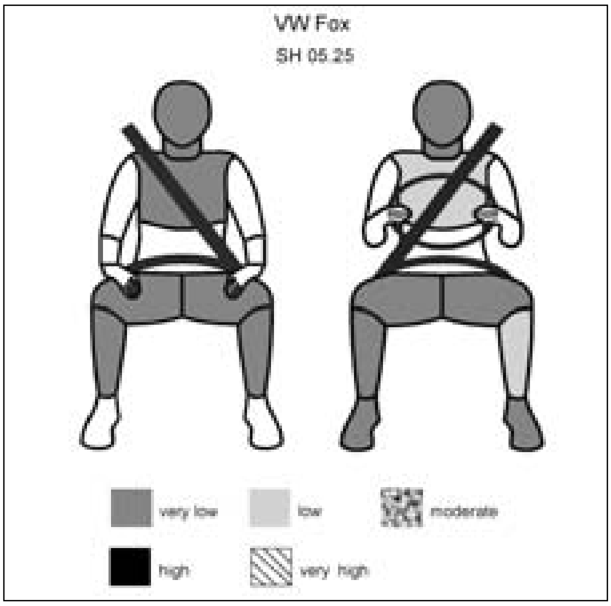


Figure 7: Driver and passenger injury risks as results of the crash test with a VW Fox

Summary and Prospects

Assessing the safety rating for the occupants of vehicles is a complex task. The first consideration must be the safety equipment of the car itself. After that the interaction of the restraint systems and the body structure as well as the behaviour of the occupants during crash loads is decisive.

When a frontal impact occurs it is necessary for the structure of the front end to transform as much impact energy as possible into deformation by controlled and harmonic crumpling. The survival space located behind the front end should remain almost intact. It is also beneficial if the pedals intrude only marginally into the footwell and transfer only low stress to the feet. Inside the passenger cell the occupants are decelerated by the restraint systems. At this stage it is important to keep the loads on passengers below the critical limits above which there is a significant risk of injury being suffered. An early and sustained deceleration of the vehicle is beneficial. Hereby the passengers should participate as early as possible. Seat-belt pre-tensioners are state-of-the-art. The expansion of the belt under the load enables a further forward movement of the occupants. This lowers the deceleration loads still further so that seat-belt force limiters can optimize the controlled forward displacement. In a subsequent stage airbags support the seat-belts and prevent injury by protecting the occupants against impacts with the steering wheel or the dashboard.

The frontal crash tests produced a multitude of results which may not always lead to the same good or even very good rating. But as described with the Euro NCAP protocol they allow a clear overall rating of the occupant safety to be made and also a comparison between single vehicles. Therefore the tests were conducted in accordance with Euro NCAP requirements, namely with a velocity of 64km/h and an offset of 40% and gave the following insights:

The behaviour of the body of the Dacia Logan was positive. There was no collapse and the survival space for the occupants remained intact. A negative finding was that the driver doors could only be opened after the test with the use of tools and considerable force. The reason for was a jammed pin-type door lock. This may complicate the recovery and rescue of injured people. Furthermore the high head loads experienced by the driver and the passenger are criticised. The reason for the high loads is probably less than ideal coordination of the seat-belts and the airbags. This is also indicated by the high measured seat-belt forces which means that the seat-belts are providing the main restraint for the passengers. The airbags also show an unusual behaviour. They deflated relatively early before contributing to the restraining of the passengers. Furthermore the rearward movement of the rigid pedals leads to higher loads on the driver's feet.

The Golf IV showed several significantly better results in the direct comparison. In the Golf the survival space also remained intact and the doors could be opened without any problems. All loads could be rated according to Euro NCAP procedure as very low to moderate. Especially the head loads were at a significantly lower level compared to those experienced in the Logans. The seat-belts equipped with seat-belt force limiters and the airbags gave a very well coordinated performance. The release mechanism of the pedals reduces the risk of bruise loads to the driver´s feet.

The VW Fox showed a better structure performance in the direct comparison with the Golfs and the Logans. The seat-belts, equipped with force limiter and pre-tensioner, combined with the airbags contributed to the low dummy loads. Consequently, the improvement in secondary safety of current new cars is there to be seen by all. Recently, occupant safety is no more a privilege of middle- or upper-class cars.

The improvement of vehicle safety is nowadays a common European goal. Against the background of accident events and vehicle population the Dacia Logan can be seen as a real economic alternative in some European countries. It could contribute to the replacement of old, badly maintained vehicles and therefore increase the general level of vehicle safety. Indeed this basically applies to Germany and other Western Europe countries, too. But in these latter regions the vehicle population is not that extremely outdated as it is in some countries of Eastern Europe or local Southern Europe. As the test results have shown for vehicles in the "8000-Euro class" a well maintained used car equipped with the relevant safety-related features can be an equal alternative. It is for the consumer to consider the importance of vehicle safety when deciding if he prefers a new low-cost vehicle or a used vehicle that could be more safe. If vehicle safety is of priority 1 and size does not matter, new cars in the "8000-Euro class" are not available but new vehicles can be purchased in the "10,000-Euro class". The achieved level of vehicle and road safety in Germany and other European countries must not be jeopardized. It has to be extended still further to keep on lowering the still unacceptable high number of severe or fatally injured people. That is why the requirements for the safety of new vehicles may not be lowered. On the contrary, the trends towards more safety have to be recognized and strengthened. Finally we must accept that this will not happen for free.

In this context consumer crash tests like those organised by Euro NCAP in addition to crash tests carried out for public magazines are welcome. This contributes to more interest being taken in secondary safety by the consumers. The consumer can include safety provisions based upon objective information when considering his buying decision. The tests made by DEKRA on behalf of "AutoBILD" have also shown that there is a further need for professional discussions to be held on the subject of the rating scheme.

References

[1] ADAC (ed.): Mobilität im Jahr 2020. Trends, Herausforderungen und Lösungsstrategien. Article #283112.1 ADAC e. V., München 2003

[2] http://www.spieqel.de/auto/aktuell/0,1518,302300,OO.html: 5000-Euro-Auto geht an den Start. Spiegel ONLINE – June 2nd 2004

[3] http://www.destatis.de/presse/deutsch/pm2005/p5150191.htm: Road accidents – prospect 2005

[4] White Paper submitted by the Commission on September 12th 2001: European transport policy for 2010: time to decide (2001) 370, September 12th 2001

[5] European Road Safety Action Programme – halving the number of road accident victims in the European Union by 2010: a shared responsibility, EU Commission (2003) 311, February 6th 2003

[6] http://www.dacia-loqan.de, official homepage of the Dacia Logan

[7] www.euroncap.com/How safe is your car?

[8] AutoBILD #15 from April 15th 2005, p. 40-44

[9] AutoBILD #22 from June 3rd 2005, p. 8-11

[10] www.euroncap.com/How safe is your car?/Dacia Logan

[11] www.euroncap.com/Test Procedures Explained

K. Okamura, K. Mori
National Research Institute of Police Science, Chiba, Japan

Y. Nishida
Institute for Traffic Accident Research and Data Analysis, Tokyo, Japan

Restraint Use Patterns for Injured Children in Japan

Abstract

Since the compulsory use of child restraints for children up to 5 years of age was introduced in 2000, restraint use among younger children has increased significantly. However, the observed rate of child restraint use plateaus at around 50%, and apparently little spillover effect has been found for older children who are not covered by the law. This report examines the restraint use patterns for children who were injured in cars in relation to driver and child passenger characteristics. Univariate and multivariate analyses were conducted to describe the association between the outcome measure (the proper use of restraints for children) and relevant variables. Better ways for parents and caregivers to improve the use of restraints for children are also discussed.

Introduction

Since the compulsory use of child restraints was mandated in 2000, the use of child restraints among Japanese child passengers has increased markedly. However, there is also evidence showing that many children are still unrestrained in cars and more could be done to improve this situation. Results of the latest survey conducted in 2005 show that the observed rate of restraint use among infants up to 1 year old was 74%, but this figure falls as the age of the children increases – 49% for children 1 to 4 years old and 30% for 5 year olds. Overall, just half of the children younger than 6 years of age (the age group targeted by the law) were appropriately restrained [1]. Of greater concern is that the proportion of child occupants observed to be appropriately restrained had begun to slightly decline in 2003 and has since leveled off. This occurred only three years after the law was enacted. Furthermore, the use of child restraints has apparently not expanded among older children who are not covered by the law, but still too small to be restrained by adult safety belts.

The problems are twofold: (a) the use of child restraints among children covered by the law is not sufficiently high, and (b) restraint use also remains low for other passenger age groups – older children and adults. The latter point has been raised for two reasons. First, if younger children or their parents became accustomed to using child restraint systems (CRS), they would continue to use CRS even when the children become older than 5 years old, until they typically outgrow booster seats. Secondly, it is not realistic to expect a miraculous rise in CRS use to occur only among young children, while the majority of older children and adult passengers in rear passenger seats are not restrained. In Japan, the rate of safety belt use among rear seat passengers is generally very low at 8% [1]. This apparently reflects the current law (or lack of regulation) in Japan where there are no punitive measures for not wearing safety belts while riding in the rear seats. This contrasts sharply with the high rate of using safety belts among drivers and front-seat passengers (92% and 80%, respectively [1]).

The present study attempts to identify the factors associated with proper use of restraints for children, and suggests recommendations for promoting the use of child restraints with a focus on the role of parents and caregivers.

Methodology

Database

The national traffic accident database of the National Police Agency (NPA) was used for this study. The NPA database consists of all police-reported accidents resulting in the injury or death of at least one person. For each accident, a minimum of 67 items of data is recorded, such as driver characteristics, collision details, environmental information. Passenger information is only compiled in cases of reported injury. At least 21 items of data items are typically recorded for each passenger involved in an accident. However, the NPA database does not provide information on passengers who do not sustain injury. Therefore, uninjured child passengers are not included within the scope of the present study.

Data coding of child restraint use patterns

The outcome measure of the present study is the proper use of restraints by child passengers. Information on the use of child restraints in the NPA database is recorded as follows: (1) appropriate CRS use, (2) CRS misuse, (3) restrained by safety belts, (4) unrestrained, (5) exempted due to illness and other reasons, and (6) unknown. Of these, (5) and (6) were excluded from the analysis. Appropriate CRS use refers to use of the appropriate safety device based on the weight and height of a child, and seating in an appropriate position within the vehicle [2]. CRS misuse is interpreted as gross misuse resulting in a child being ejected from the CRS due to an accident, and is typified by the loose attachment of safety belts to the CRS and loose harness straps.

Parameters (1) to (4) were re-coded separately for younger children (up to 5 years old) and older children (6 to 12 years old) as shown in Table 1. For younger children, cases where they were appropriately restrained by CRS were re-coded as 'properly restrained', and others (parameters (2), (3) and (4)) were re-coded as 'not properly restrained'. For older children, cases where they were appropriately restrained by CRS or restrained by safety belts (parameters (1) and (3)) were re-coded as properly restrained. The use of safety belts by children younger than 13 years of age may be considered a premature graduation from CRS and therefore inappropriate. However, since the purpose of this study is to investigate the use of child restraints at the time of an accident in conjunction with the current law, parameter (3) was re-coded as properly restrained for this age group.

	Outcome measure	
	Properly restrained	Not properly restrained
0-5 years olds	Appropriate CRS use	CRS misuse Unrestrained Restrained by safety belt
6-12 years olds	Appropriate CRS use Restrained by safety belt	CRS misuse Unrestrained

Table 1: Re-coding of child restraint use

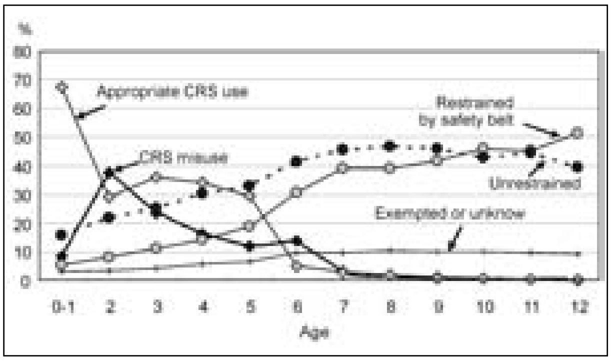


Figure 1: Restraint use patterns in percentage by age of children injured or killed

Data sets

Original data set

The following cases were extracted from the NPA database to form a separate data set: accidents in which child passengers up to 12 years old were injured or killed during the years 2004 and 2005 in privately owned passenger cars. This data subset is called the original data set. Large vehicles, school buses, taxis, and rented cars were excluded. This original data set includes information on 47,283 children who were injured or killed in car accidents.

Children up to 5 years old are the target group of compulsory CRS use under the current law. Older children 6 to 12 years old, covering all primary school-age pupils, were also included for analysis. Figure 1 shows the restraint use pattern for children who were injured or killed as obtained from the original data set. The percentage of appropriate CRS use is relatively high only for infants up to 1 year old, but drops below 40% for children 2 to 5 years old. Fewer than 5% of the children injured or killed who were at least 6 years old used CRS appropriately. Conversely, the percentage of children who were restrained by safety belts or not restrained at all increases with the children's age.

Not-at-fault rear-end collision data set

Since the NPA data provides information only on injured passengers, it is quite possible that certain types of accidents are overrepresented while others are underrepresented in the original data set. For example, a previous data analysis of Japanese child occupants showed that a higher proportion of injured child passengers were found to be unrestrained in head-on collisions and single-vehicle accidents than in rear-end collisions [3]. It is assumed that head-on collisions and single-vehicle accidents are overrepresented in the data due to the high speed at impact, thus reflecting a higher incidence of injury to child passengers, which results in higher percentage of the injured child passengers found to be unrestrained. This is not necessarily due to a lower rate of CRS use among those involved in head-on collisions. The main focus of the present study is to identify the demographic and behavioral characteristics of occupants associated with the proper use of restraints under existing regulations. To this end, it would be best to eliminate the effects of certain factors if they excessively influence data representation.

Drivers who were involved in rear-end collisions as the party least responsible can be considered a pseudo-sample of drivers who happened to be involved in an accident “by chance”. Admitting that this is only a rough estimate, much of the bias influencing the use of child restraints could be eliminated by focusing on those involved in a rear-end collision, thus making it possible to identify the factors associated with the use of restraints by children. It is indeed true that this estimate still suffers from selection bias, for example, inflated restraint use rate, and this is discussed later in this paper. This “quasi-not-at-fault driver subgroup” data set was created by extracting the drivers whose vehicles were struck by another vehicle in a rear-end collision as the party least responsible, together with information on child passengers. This data subset is called the not-at-fault rear-end collision data set. This data set consists of 21,352 pairs of drivers and child passengers, accounting for 45.2% of the cases in the original data set. Almost all (99.3%) drivers were judged to assume no legal responsibility for an accident, and 90.2% of the drivers involved were actually braking to stop their cars uponrealizing the imminent danger. Nine children were killed within 24 hours of an accident (0.04%), and 63 were seriously injured (0.3%), meaning that virtually all the children suffered minor injuries (99.7%) – typically neck sprain or whiplash injury.

Data analysis

Based on the not-at-fault rear-end collision data set, Pearson’s chi-square and t-statistics were used to compare the demographics of occupants (age, gender, and license status), characteristics of travel (purpose, time of day, and day of the week), and other relevant variables (use of a safety belt by the driver, seating position, and total number of occupants) to the outcome measure (the proper use of restraints for children). After univariate associations with outcome were calculated, correlation coefficients (r) were computed to check the relationship between independent covariates of interest. Logistic regression was then applied to compute the odds ratio, adjusted for possible confounding variables.

Results

Univariate analysis

Table 2 summarizes univariate association with the outcome measure for younger children (up to 5 years old). A significant association was found between the outcome and time of day, day of the week, driver gender, driver age group, license status, purpose of travel, use of a safety belt by the driver, number of occupants, and the age of children. No significant association was found regarding the type of car and seating position of the children. Moreover, no association was found regarding the gender of children, results of alcohol tests, and the use of mobile phones while driving (not shown in the tables). Further detailed information on the occupants is not available, such as how many adults and children were seated together in a car.

Table 3 summarizes univariate association for older children (6 to 12 years old). A significant association was found between the outcome and day of the week, driver gender, driver age group, type of car, purpose of travel, use of a safety belt by the driver, number of occupants, and the seating position and age of the children. No significant association was found regarding the time of day and driving license status.

Multivariate analysis

In order to simultaneously adjust for possible confounders, multivariate analysis was conducted. Based on univariate analysis, any variable whose univariate test yielded a p-value <0.05 was included in the multivariate model. Table 4 and Table 5 show adjusted odds ratio (OR) and a 95% confidence interval (CI) for younger and older children, respectively.

As shown in Table 4, six variables were significant predictors of the proper use of restraints by younger children, when adjusted for the effects of other variables. The OR of proper restraint use was 14% lower at night compared with daytime (OR=0.86). Drivers aged 50 and older were less likely to restrain children properly, while drivers in their 30s

Variables			Properly restrained	Not properly restrained	x^2 or *t*
Time of day (%)	Day		81.0	77.7	X^2=16.80[3]
	Night		19.0	22.3	
		N	4945	4922	
Day of week (%)	Weekdays		57.8	52.9	
	Weekends/ bank holidays		42.2	47.1	
		N	4945	4922	
Driver gender (%)	Man		37.1	42.3	X^2=28.21[3]
	Woman		62.9	57.7	
		N	4945	4922	
Driver age group (%)	29 and under		29.0	31.7	X^2=56.55[3]
	30-39		55.0	57.0	
	40-49		9.1	7.2	
	50-59		4.1	2.5	
	60 and older		2.8	1.5	
		N	4945	4922	
Driving license status (%)	Valid		99.9	99.8	X^2=5.45[1]
	Notvalid		0.1	0.2	
		N	4945	4920	
Type of car (%)	Passenger car		69.9	68.2	X^2=3.36
	Mini car <660cc		30.1	31.8	
		N	4945	4922	
Purpose of travel (%)	Commuting		1.8	1.6	X^2=24.75[3]
	Business		0.6	0.7	
	Leisure		14.3	17.7	
	Shopping		33.2	32.3	
	Visit		17.8	17.8	
	Escort		8.3	8.0	
	Other private		24.0	22.0	
		N	4945	4920	
Driver belt (%)	Belted		99.2	97.9	X^2=30.27[3]
	Unbelted		0.8	2.1	
		N	4919	4898	
Seating position of child (%)	Front seat		25.3	26.3	$X^2$1.22
	Rear seat		74.7	73.7	
		N	4926	4876	
Number of occupants	Average (SD)		3.04 (0.96)	3.41 (1.15)	*t*=17.3[3]
	Mode		3	3	
		N	4945	4922	
Child age	Average (SD)		2.28 (1.46)	3.06 (1.39)	*t* =-27.09[3]
	Mode		1	2	
		N	4945	4911	
[1] p<.0.5, [2] p< 0.1, [3] p<.00.1					

Table 2: Univariate analysis of proper restraint use for younger children (up to 5 years old)

Variables			Properly restrained	Not properly restrained	x^2 or *t*
Time of day (%)	Day		73.2	73.1	X^2=0.02
	Night		26.8	26.9	
		N	5044	4959	
Day of week (%)	Weekdays		45.8	41.5	X^2=19.22[3]
	Weekends/ bank holidays		54.2	58.5	
		N	5044	4959	
Driver gender (%)	Man		34.5	41.7	X^2=57.88[3]
	Woman		65.7	58.3	
		N	5044	4959	
Driver age group (%)	29 and under		6.0	5.3	X^2=28.34[3]
	30-39		56.8	53.2	
	40-49		29.7	34.2	
	50-59		3.5	4.0	
	60 and older		3.9	3.3	
		N	5044	4959	
Driving license status (%)	Valid		100.0	99.9	X^2=2.70
	Notvalid		0.0	0.1	
		N	5044	4959	
Type of car (%)	Passenger car		66.6	69.5	X^2=10.05[2]
	Mini car <660cc		33.4	30.5	
		N	5044	4959	
Purpose of travel (%)	Commuting		1.1	0.9	X^2=81.77[3]
	Business		0.7	0.5	
	Leisure		16.0	22.4	
	Shopping		31.5	30.0	
	Visit		16.5	16.8	
	Escort		11.5	11.0	
	Other private		22.8	18.4	
		N	5044	4959	
Driver belt (%)	Belted		99.9	98.1	X^2=79.32[3]
	Unbelted		0.1	1.9	
		N	5035	4946	
Seating position of child (%)	Front seat		59.0	8.5	X^2=2842.10[3]
	Rear seat		41.0	91.5	
		N	5036	4952	
Number of occupants	Average (SD)		3.01 (1.10)	3.66 (1.29)	*t*=27.22[3]
	Mode		2	3	
		N	5044	4959	
Child age	Average (SD)		9.04 (2.00)	8.66 (1.98)	*t* =-9.59[3]
	Mode		11	6	
		N	5044	4959	
[1] p<.0.5, [2] p<.0.1, [3] p<.00.1					

Table 3: Univariate analysis of proper restraint use for older children (6 to 12 years old)

were most likely to use CRS properly. Drivers with an invalid license (suspended due to driving violations or accidents) were less likely to restrain children properly than drivers with a valid license (OR=0.24). Unbelted drivers were less likely to restrain children properly than belted drivers (OR=0.35). Children were less likely to be restrained properly when the total number of occupants increased (OR=0.73), and with increasing age of the children (OR=0.69).

Variables		Adjusted OR	95% CI
Time of day	Day	1.00	
	Night	0.86	0.77-0.95[2]
Day of week	Weekdays	1.00	
	Weekends/bank/ holidays	1.01	0.92-1.10
Driver gender	Woman	1.00	
	Man	0.96	0.87-1.06
Driver age group	29 & under	1.00	
	30-39	1.19	1.08-1.31[3]
	40-49	1.09	0.92-1.29
	50-59	0.67	0.53-0.86[2]
	60 & older	0.70	0.52-0.96[1]
Driver licence	Valid	1.00	
	Not valid	0.24	0.06-0.91[1]
Purpose of travel	Commuting	1.00	
	Business	1.09	0.60-1.98
	Leisure	1.12	0.80-1.57
	Shopping	1.08	0.78-1.49
	Visit	1.10	0.79-1.54
	Escort	1.21	0.85-1.72
	Other private	1.22	0.87-1.69
Driver belt	Belted	1.00	
	Unbelted	0.35	0.24-0.52[3]
Number of occupants		0.73	0.70-0.76[3]
Child age		0.69	0.67-0.71[3]
[1] p<.0.5, [2] p<.0.01, [3] p<.001 Wald test			

Table 4: Adjusted odds ratios of proper restraint use for younger children (up to 5 years old)

Variables		Adjusted OR	95% CI
Day of week	Weekdays	1.00	
	Weekends/bank/ holidays	1.00	0.92-1.09
Driver gender	Woman	1.00	
	Man	1.02	0.93-1.13
Driver age group	29 & under	1.00	
	30-39	0.94	0.78-1.13
	40-49	0.97	0.80-1.78
	50-59	1.07	0.81-1.42
	60 & older	0.88	0.67-1.17
Type of car	Passenger car	1.00	
	Mini car < 660cc	0.93	0.85-1.02
Purpose of travel	Commuting	1.00	
	Business	1.48	0.75-2.91
	Leisure	1.04	0.68-1.58
	Shopping	1.09	0.72-1.63
	Visit	1.05	0.69-1.59
	Escort	0.96	0.63-1.47
	Other private	1.44	0.95-2.18
Driver belt	Belted	1.00	
	Unbelted	0.06	0.03-0.13[3]
Number of occupants		0.62	0.59-0.64[3]
Child age		1.09	1.07-1.1[3]
[1] p<.0.5, [2] p<.0.01, [3] p<.001 Wald test			

Table 5: Adjusted odds ratios of proper restraint use for older children (6 to 12 years old)

Table 5 shows the predictors of the proper use of restraints by older children when adjusted for independent variables. After conducting regression analysis using all nine independent variables as possible confounders (obtained from the results shown in Table 3), it was noted that the variable of child's seating position could well act as a synonymous variable with the outcome (r=-0.53). In other words, when children were seated in the rear seat, most were unrestrained. When children sat in the front passenger seat, they were mostly restrained. Therefore, the seating position variable was excluded from the regression model. Three variables were significant independent predictors. When drivers were unbelted, children were also likely to be unrestrained (OR=0.06). As the total number of occupants increased, children were less likely to be properly restrained (OR=0.62). With increasing age, children were more likely to be restrained (OR=1.09).

Conclusion

Summary of the results

- The present study investigated the behavioral and demographic characteristics of drivers and child passengers who were involved in not-at-fault rear-end collisions. It was apparent that restraint use patterns differed completely between children up to 5 years old (the target of the current law) and children 6 to 12 years old.
- Univariate analysis of younger children (up to 5 years old) showed that such children were less likely to be properly restrained when accidents occurred at night, on weekends, or on holidays, during leisure trips, when men or older people drove the car, drivers had an invalid license, drivers were unbelted, there were more occupants in the car, and when the children were older.
- Univariate analysis of older children (6 to 12 years old) showed that such children were less likely to be belted when accidents occurred on weekends or on holidays during leisure trips, when men and older people drove the car, children rode in passenger cars, drivers were unbelted, children were seated in the rear seat, there were more occupants in the car, and when the children were younger.

- When adjusted for confounders, six predictors of the proper use of restraints for younger children were identified. The following variables significantly decreased the odds ratio of proper restraint use: nighttime accidents, older (>50) drivers, drivers with an invalid license, unbelted drivers, more occupants in the car, and older children.
- When adjusted for confounders, three predictors of the proper use of restraints for older children were identified. The following variables significantly decreased the odds ratio of proper restraint use: unbelted drivers, more occupants in the car, and younger children.

Interpretation of the results

- For both younger and older children, the use of a safety belt by the driver, age of injured children, and total number of occupants are apparently the most powerful predictors of the proper use of restraints for children. The relationship between the use of a safety belt by the driver and use of restraints for children has already been established in previous studies (for example [4]). Although there are very few reportedly unbelted drivers who were involved in not-at-fault rear-end collisions, the use of child restraints did mirror the use of a safety belt by the driver. It was also indicated that drivers are only keen to properly restrain very young children. It is quite likely that instead of continuing to use a child seat or booster seat, many parents simply discard the seats before children outgrow the CRS. Therefore, older children – unless seated in the front, as is often the case when there are only two occupants in the car (the driver and a child) – are not restrained at all. When there are more than two occupants in the car, chances are that the children sit in the rear seat and are simply left unrestrained.
- It may well be that existing regulations, although unintentional, serve to accelerate a premature graduation from the CRS for children who are too small to be restrained by safety belts and instead are left completely unrestrained, which is facilitated by situations where most adult passengers in the rear seat do not wear safety belts. Therefore, the compulsory use of restraints by both adults and children should be introduced and promoted hand in hand.
- There seems to be certain tendencies observed among drivers who do not restrain younger children properly: older drivers, possibly grandparents, are clearly less likely to use CRS properly, indicating that this particular generation would need to be informed of existing regulations and why it is necessary to use the CRS. Secondly, drivers with an invalid license, usually due to multiple driving violations or at-fault accidents, were unlikely to restrain children properly. In contrast, such specific driver characteristics were not found among those who had older child passengers in the car.
- Given the generally low number of fatalities involving child passengers in car accidents (the percentage being 0.2% according to the original data set), it is extremely difficult to increase the perception among caregivers regarding the inherent risk of misusing CRS. Furthermore, many characteristics of child restraint use and motor vehicle travel tend to reduce the perception of such risk, such as motor vehicle travel and having child passengers being perceived as a controllable, common, non-catastrophic, and familiar risk. It may therefore be necessary to arouse a sense of outrage by appealing to people's fears in order to promote the perception of CRS misuse as a serious risk [5].
- Some limitations should be considered when interpreting the results. Child passengers who were not injured in car accidents are omitted from the NPA database, and the results may not be applicable to driver-child passenger groups involved in accidents other than not-at-fault rear-end collisions. Finally, the police-reported use of restraints is known to be inflated due to the false reporting by occupants seeking to avoid being ticketed for such violation, and this is more of a factor in accidents involving minor injury where the occupants typically exit their vehicles before the police arrive [5].

References

[1] National Police Agency: Japan Automobile Federation: Results of survey on restraint use. http://www.npa.go.jp/koutsuu/index.htm (accessed on May 31st 2006)

[2] P. BOASE, B.A. JONAH, N. DAWSON: Occupant restraint use in Canada. Journal of Safety Research, 35, pp. 223-229, 2004

[3] K. OKAMURA: Behavioral characteristics of drivers whose child occupants were injured or killed in the car (in Japanese). Gekkan Kotsu, 433, pp. 15-28, 2005

[4] T.R. MILLER, R.S. SPICER, D.C. LESTINA: Who is driving when unrestrained children and teenagers are hurt? Accident Analysis & Prevention, 30, pp. 839-849, 1998

[5] K.E. WILL, E.S. GELLER: Increasing the safety of children's vehicle travel: from effective risk communication to behavior change. Journal of Safety Research, 35, pp. 263-274, 2004

Poster Session:
Short Presentation

L. Hannawald

Y. Page, T. Hermitte

E. Tomasch, H. Steffan

R. de Lange, R. Happee, L. van Rooij, X.J. Liu

C. Klootwijk, R.H. Hoogvelt

D.A. Aylor, J.M. Nolan, D.S. Zuby, B.C. Baker

F. Kramer, W. Werner, J. Reimer

L. Hannawald
Accident Research Unit, University of Technology Dresden, Germany

Accident Research in Germany – Experiences of an Interdisciplinary Project

Abstract

The accident research project in Dresden was founded in July 1999. To date over 6.000 crash investigations have been undertaken. About 10.000 vehicles have been documented and over 13.000 participants have been debriefed. But there is much more than this scientific success.

Because of the interdisciplinary character between the medical and technical focus, the project affords an important contribution for the education of the involved students. Over 200 students of different fields of study have got experiences not only for the occupational career.

This lecture describes the additional effects of the accident research project regarding the education of the students, the capacity for teamwork and learning about dealing with accident casualties.

Form of Organization

The Accident Research Unit at the University of Technology Dresden is part of the GIDAS project, established by the German Automotive Industry Research Association (FAT) and the Federal Road Research Institute (BASt). Approximately 1 million inhabitants live in this area of about 3.000km^2

Work Scope

During the shift the team consists of two technicians, one medical student and one coordinator. Especially at the accident side the teamwork is of high priority. The team is especially provided with different cameras and measuring instruments for documentation, photogrametry and measuring purposes.

Furthermore the following data are collected:

- environmental conditions,
- particular construction features of the vehicles involved,
- design of the roads,
- traffic control.

The vehicles involved in the traffic accident are carefully investigated regarding:

- vehicle deformation,
- points of passengers' impact or off-road users outside the vehicle,
- technical identification data, vehicle type and equipment.

All persons involved are interviewed about:

- sequence of events during accident,
- persons' height and weight,
- driver's license with possible special conditions and other details.

Vehicles that cannot be investigated at the accident site are inspected the following day by another technical student.

The medical student drives to the scene of the traffic accident with an extra research vehicle. At the scene the medical employee supports the rescue units and starts the documentation of the injury patterns.

To complete this collection of data, information about the subsequent treatment of the injured in the hospital is added. The type, severity and location of all the injuries are documented.

Up to now more than 6.000 accidents are investigated by the accident research project in Dresden. Each accident side was measured and detailed drawing and extensive picture records were made. About 10.000 vehicles were inspected. More than 13.000 single collisions were detected and reconstructed. All in all about 20.000 single injuries were diagnosed by more than 7.500 injured participants in the last 7 years.

More than 3.000 single facts have to be coded by the students for each case. The complete duration for handling the data is about 25 hours per case.

These many facts indicate the high claim and interdisciplinary approach of the project. The correlation between technical and medical facts has a need for a complex teamwork at accident side and the later diagnosis and coding of the data.

Education of Students

About 50 students are employed continually for the documentation of accidents in the project who major either in automotive engineering or human medicine.

Since 1999 more than 220 students of different fields of studies get a special education at the project.

Every driver takes a great responsibility using the special right of way through the use of siren and flashing blue lights on the way to the accident site. Therefore all drivers of the research vehicles are trained on the legal background and the practical handling using the special right of way, on a quarterly basis. More than 25 of these trainings were implemented since 1999. In addition, a driving safety and handling training is offered in the same period of time.

Furthermore mainly the technical employees are instructed in providing advanced first aid.

They have to learn and train interview techniques, dealing with accident casualties and the understanding of technical, medical an road building aspects regarding the accident casuality.

Only extensive education of the technical students could provide such an intensive work. The same is obtained by medical students.

All students get an 2 months special education and single certification before they can work independently at the accident scene.

Additionally there were made over 50 seminar papers, diploma and master thesis in the last 7 years at the Accident Research Unit in Dresden.

Capacity for Teamwork

All students have learned to deal with injured participants up to fatalities at the accident scene. The ability to work in a team is the most important criteria for employment as a student in the research team. Further competences especially in psychological interview with the accident participants are important, too.

Further additional facts are the interdisciplinary effects for the students and the rational work mode they have learned. Most of the students talk about an individual learning process during the employment. Not less talk about a much more defensive individual characteristic of driving and personal maturity.

So the accident research project is more and more a secondary education for the employeers. The function is more than investigation of accidents.

Nevertheless the duration of employment is not longer than 2 years normally. After that time the students complete their study and make an application for employment in the free market mostly with very good chances of success.

Y. Page, Th. Hermitte
on behalf of the Trace Consortium
Laboratoire d'Accidentologie, de Biomécanique et d'études du Comportement Humain, Nanterre, France

The TRACE Project: An Initiative to Update Accident Causation Issues and Evaluate the Safety Benefits of Technologies

The Integrated Safety programme and the eSafety initiative stress that the development of Intelligent Transport Systems in vehicles or on roads (and especially in the safety field) must be preceded and accompanied by a scientific accident analysis encompassing two main issues:

- The identification and the assessment (in terms of lives saved and accidents avoided), among possible safety technologies, of the most promising solutions that can assist the driver or any other road users in a normal road situation or in an emergency situation or, as a last resort, mitigate the violence of crashes and protect vehicle occupants, pedestrians, and two-wheelers in case of a crash or a rollover.
- The determination and the continuous up-dating of the aetiology, i.e. causes, of road accidents (as well as the causes of injuries) and the assessment of whether the existing technologies or the technologies under current development address the real needs of road users infered from accident and driver behaviour analyses.

The general objective of the TRACE project (Traffic Accident Causation in Europe) is to provide the scientific community, the stakeholders, the suppliers, the vehicle industry and the other Integrated Safety program participants with a global overview of the road accident causation issues in Europe, and possibly overseas, based on the analysis of any and all current available databases which include accident, injury, insurance, medical and exposure data (including driver behavior in normal driving conditions). The idea is to identify, characterise and quantify the nature of risk factors, groups at risk, specific conflict driving situations and accident situations; and to estimate the safety benefits of a selection of technology-based safety functions. Expected outcomes are essentially reports.

Besides this, TRACE proposes three different research angles for the definition and the characterization of accident causation factors, TRACE proposes to improve the methods actually used in accident analysis (diagnosis and evaluation). And finally, TRACE intends to base the analyses on available, reliable and accessible existing and on-going databases (access to which will be greatly facilitated by a series of partners highly experienced in safety analysis, coming from 8 different countries and having access to different kinds of databases, in-depth or regional or national statistics in their own country, and for some of them in additional countries).

The project is to last 2 years and involves 16 full partners and 6 sub-contractors for a total of 386 man-months.

E. Tomasch, H. Steffan
Vehicle Safety Institute, Graz University of Technology, Graz, Austria

ZEDATU (Zentrale Datenbank tödlicher Unfälle in Österreich) A Central Database of Fatalities in Austria

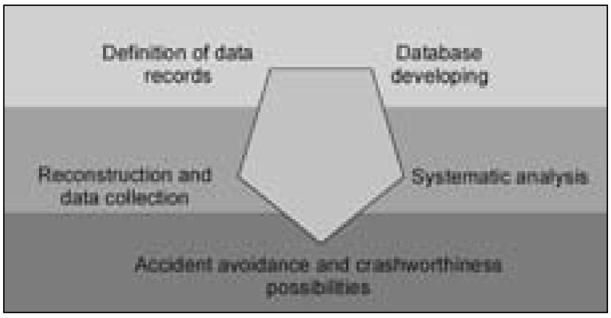


Figure 1: Project structure

Abstract

Due to recent years accident avoidance and crashworthiness on Austrian roads were mostly developed on national statistics and on-scene investigation respectively. Identification and elimination of black spots were main targets. In fact many fatal accidents do not occur on such black spots and black-spot investigation has reached a limit. New methods are required and therefore the Austrian Road Safety Programme was introduced by the Austrian Ministry of Transport, Innovation and Technology. The primary objective is the reduction of fatalities and severe injuries. Graz University of Technology initiated the project ZEDATU (Zentrale Datenbank tödlicher Unfälle) with the goal to identify similarities in different accident configurations. A matrix was established which categorizes risk and key factors of participating parties. Based on this information countermeasures were worked out.

Introduction

Besides of national statistics there is no database available allowing a (comparable) in-depth analysis. Even if the national database was enhanced for black-spot management driver's and pedestrian's behaviour can not be analysed. In-depth accident investigation which for instance includes vehicle performance in different crash scenarios only can be studied with a more comprehensive range of data fields.

National statistics can be seen as a base level with an assessment of accident situations and examination of trends. An intermediate level identifies hazardous road locations and in-depth accident investigation will take into account causation mechanisms or injury prevention measures, too. ZEDATU was initiated to examine road accidents on an in-depth basis and to identify similarities in different accident configurations which have overall validity. Many accidents are single vehicle accidents which do not take place at black spots but could have similar circumstances. Risk and key factors were developed to scrutinize causation conditions.

Project Structure

The project was divided into three levels with five Work Packages (Figure 1).

Definition of data records and developing of the database

The definition of the data records was based on the STAIRS (Standardisation of Accident and Injury Registration Systems) [1] protocol and enhanced by several different European projects, namely PENDANT (Pan-European Co-ordinated Accident and Injury Databases) [2], RISER (Roadside Infrastructure for Safer European Roads) [3] and ROLLOVER (Improvement of Rollover Safety for Passenger Vehicles) [4]. In addition data fields of national statistics were implemented into the database to ensure correlation with road accidents.

Accident risk and causation factors (Figure 2) were one of the basic parts during the project. Identification of the key factors was mainly found from police and expert technical reports, pictures from scene or witness reports and accident reconstruction respectively.

Reconstruction and analysis

Accident reconstruction was performed with PC Crash. The possibilities to avoid an accident of all participating parties were determined. Figure 3 shows an accident at a junction from the first

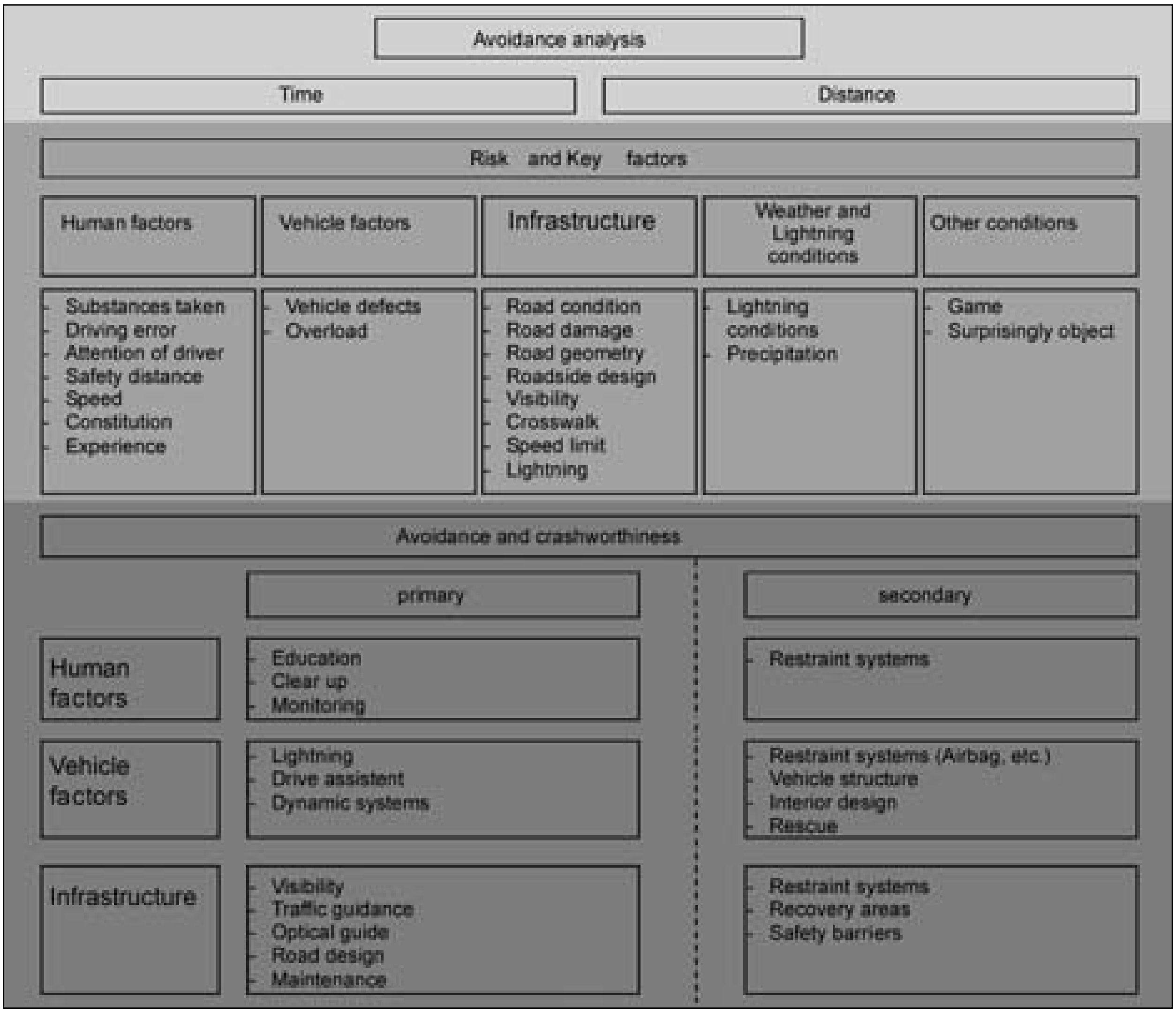


Figure 2: Matrix for accident analysis

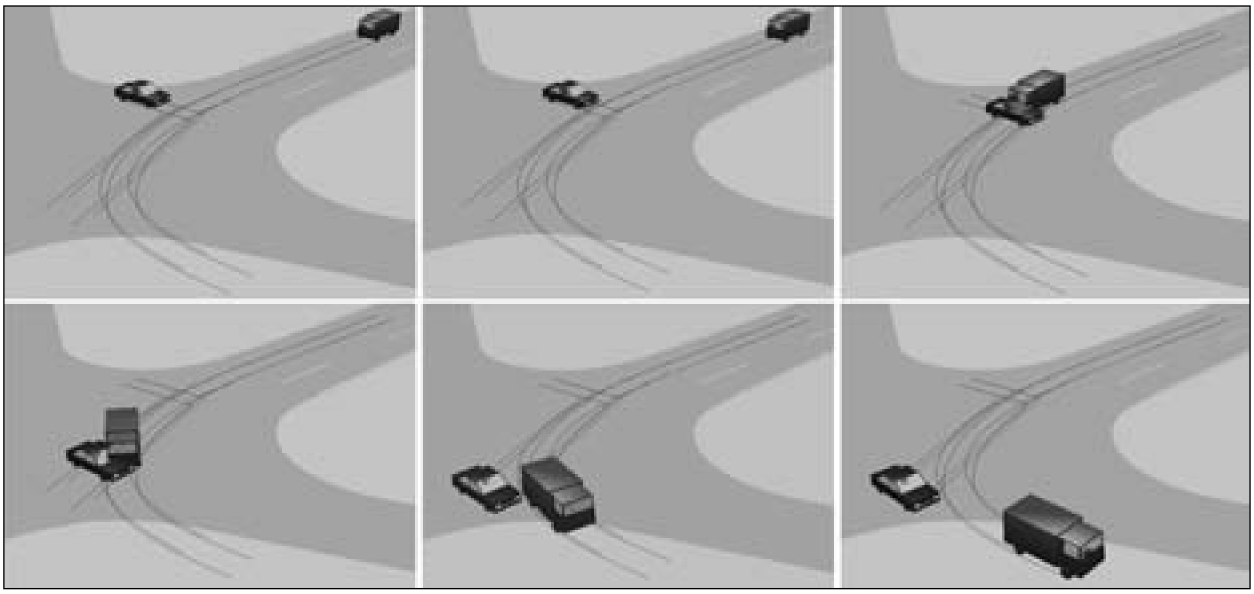


Figure 3: Accident sequences

movement of the smaller vehicle until the rest positions.

An analysis was made in a systematic manner. Firstly all Austrian accident types were studied and finally rollover and motorcycle accidents were analyzed separately. Within each accident type human factors such as use of seat-belt, age, gender etc. were comprised. Risk and key factors were investigated and analyzed for each accident type separately.

Accident avoidance and crashworthiness possibilities

Based on the analysis results a proposal has been worked out which included countermeasures for driver, vehicle and infrastructure. These countermeasures are based on primary or secondary safety. (Remark: Education and monitoring of seat-belt usage can be categorized as primary safety. Improvement of restraint systems or vehicle structure can be categorized as secondary safety.)

Results

A short summary of analysis provided that in single vehicle accidents only 40% of occupants were using the seat-belt for sure. Investigation of car accidents only show that close to 13% of analyzed fatal accidents resulted in a rollover. Additionally, rollovers mostly occurred in single vehicle accidents. 90% of the unbelted occupants were ejected during a rollover. Dangerous objects at the road side were identified as trees, poles or embankments (cut and fill slopes).

Discussion

Gathering the accident cases it was figured out that documentation of accidents varied in quality. Particularly pictures taken from scene and vehicles were inadequate. Only about 20% had good or perfect quality. For a huge number of single vehicle accidents documentation had poor quality, especially when only the driver was involved. The reason was found in Austrian's legislation. There is no law to punish self-injuries – hence little effort is taken by the police in investigating single car accidents thoroughly. Coding AIS (Abbreviated Injury Scale) was impossible for most of the fatal injured participants when no autopsy was made.

Conclusion

Currently no detailed in-depth fatality database is available in Austria nor in other European countries. ZEDATU has detailed information regarding human, vehicle and infrastructure. Due to the accident matrix it is possible to identify risk and key factors for each accident. STAIRS as the fundamental protocol should guarantee a harmonized data collection. ZEDATU based on STAIRS and enhanced by several European projects may provide accident data in high detail.

References

[1] http://www.lboro.ac.uk/research/esri/vsrc/stairs/index.htm

[2] http://www.vsi.tugraz.at/pendant/

[3] www.mvs.chalmers.se/~thomson/RISER/index.html

[4] http://www.vsi.tugraz.at/rollover/

R. de Lange, L. van Rooij
TNO Science and Industry, Automotive Safety, Delft, The Netherlands

R. Happee
TNO Automotive Safety Solutions, Delft, The Netherlands

X.J. Liu
TNO Automotive China, Shanghai, China

Validation of Human Pedestrian Models Using Laboratory Data as well as Accident Reconstruction

Abstract

Human pedestrian models have been developed and improved continually. This paper shows the latest stage in development and validation of the multibody pedestrian model released with MADYMO. The biofidelity of the multibody pedestrian model has been verified using a range of full pedestrian-vehicle impact tests with a large range in body sizes (16 male, 2 female, standing height 160-192cm, weight 53.5-90kg). The simulation results were objectively correlated to experimental data. Overall, the model predicted the measured response well. In particular the head impact locations were accurately predicted, indicated by global correlation scores over 90%. The correlation score for the bumper forces and accelerations of various body parts was lower (47-64%), which was largely attributed to the limited information available on the vehicle contact characteristics (stiffness, damping, deformation). Also, the effects of the large range in published leg fracture tolerances on the predicted risk to leg fracture by the pedestrian model were evaluated and compared with experimental results. The validated mid-size male model was scaled to a range of body sizes, including children and a female.

Typical applications for the pedestrian models are trend studies to evaluate vehicle front ends and accident reconstructions. Results obtained in several studies show that the pedestrian models match pedestrian throw distances and impact locations observed in real accidents. Larger sets of well documented cases can be used to further validate the models especially for specific populations as for instance children. In addition, these cases will be needed to evaluate the injury predictive capability of human models.

Ongoing developments include a so-called facet pedestrian model with a more accurate geometry description and a more humanlike spine and neck and a full FE model allowing more detailed injury analysis.

Introduction

Statistics show that pedestrian accidents are a major source of fatalities and injuries. In the European Union alone, about 6,250 pedestrians are killed every year in road accidents, while over 100,000 are severely injured (OTTE, 2001; EEVC, 1998). When the total amount of world-wide traffic fatalities estimated by MACKAY (2000) at 950,000 are combined with the World Bank (2003) statement that 65% of all traffic fatalities involve pedestrians, a yearly world-wide pedestrian traffic fatality number of 615,000 is estimated.

As the vehicle front is considered the cause for a significant amount of all pedestrian injuries, a considerable amount of effort has been put in recent years into designing strategies to reduce the aggressiveness of the vehicle exterior. In particular, changes in the design of the vehicle front and bonnet are considered to be effective, where both shape and stiffness of the vehicle are important parameters. Optimizing the vehicle front for pedestrian protection while maintaining the vehicle crashworthiness is a complicated and timely process. Mathematical simulations using biofidelic pedestrian models can help to efficiently assess the pedestrian protection in the early stages of the design process. In addition, mathematical modelling is a valuable tool to reconstruct pedestrian vehicle accidents as the models can provide insight into relevant crash parameters and into the kinematics of the pedestrian involved.

This paper describes the development and validation of the MADYMO human pedestrian models. In addition, typical applications and future developments are discussed using information from earlier studies done with the human pedestrian models. Special attention is paid to accident reconstruction to show the capabilities of the current models and to indicate how accident cases could improve the models validation.

Model Development and Validation

The pedestrian model (shown in Figure 1) presented in this paper has been created using multibody techniques available in the software package MADYMO. A first version of this model has been developed in a cooperation with Chalmers University as reported by de LANGE, HAPPEE, YANG and LIU (2001). A major update of the MADYMO pedestrian model has been published by HOOF et al. (2003) and the model is released with MADYMO 6.2.2. The outer surface of the model is represented by 64 ellipsoids and is based on the anthropometry data of an average Western European male obtained from the RAMSIS software (SEIDL, 1994).

The human-body pedestrian biomechanical data for the joints and segment parts were implemented from a variety of publications, together with detailed validation for the whole body as well as components. The majority of this data is concerned with the 50th percentile adult male model.

The contact characteristics for the various body regions were based on data found in literature and optimized in simulations of a large range of PMHS impactor tests on various body parts. The different impactor test configurations simulated are shown in Figure 2.

The validation results obtained with the pedestrian model are published by van HOOF et al. (2003). In general, the model approximates the measured PMHS response well, especially when the large range in test conditions and impacted body parts is considered.

A flexible leg model was implemented. Three spherical joints are specified in the upper leg dividing the upper leg (femur) into four equal parts. For the lower leg, also three joints are specified. For the required bending stiffness, a rotational force model was implemented. Angular stiffness functions were derived from simulations of quasi static bending tests done by YAMADA (1970).

In car-pedestrian collisions often fracture of the leg occurs. Therefore leg fracture is implemented in the human pedestrian model. Fracture joints were sited at the middle femur joint and at each of the tibia bending joints. The 50th percentile fracture levels were derived from literature.

Model validation has been made on both the body segments and on whole body simulations. For the verification of the lower extremity, the lower extremity model was separated from the full body pedestrian model. Impact tests with real human lower extremity specimens (KAJZER et al. 1990 and 1993) were simulated. In addition, three different sets of PMHS pedestrian-vehicle impact tests have been simulated to verify the biofidelity of the pedestrian model. Since PMHS subjects of different anthropometries were used in the tests, the pedestrian model was scaled to the specific body dimensions of each PMHS subject prior to simulating the corresponding test. In total 18 subjects (16 male, 2 female) were used in these tests, ranging in height from 160-192cm and in weight from 53-90kg. The results of the simulations were objectively compared with available experimental data. An extended description of the validation simulations and results can be found in van HOOF et al. (2003). From the extended validation of the pedestrian models it can be concluded that:

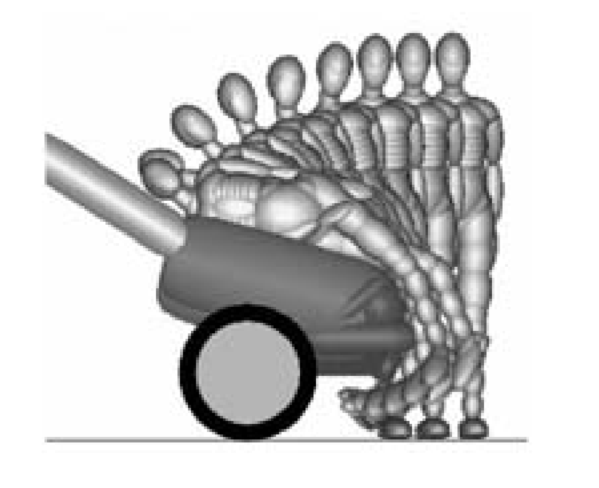


Figure 1: The MADYMO mid-size male pedestrian model

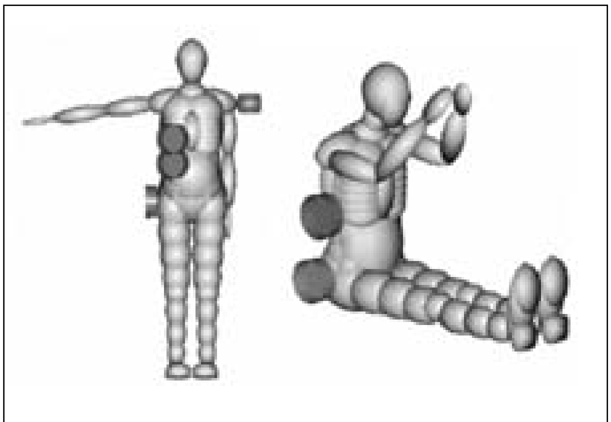


Figure 2: Range of impactor test configurations used for model validation

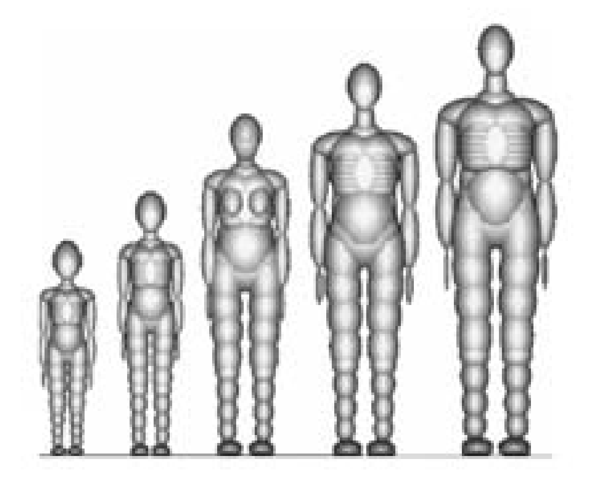


Figure 3: From left to right: models of 3 and a 6 year old child, small female, mid-size male and large male

	3 yr. old child	6 yr. old child	Small female	Mid-size male	Large male
Standing height [m]	0.95	1.17	1.53	1.74	1.91
Seated height [m]	0.55	0.64	0.81	0.92	1.00
Shoulder width [m]	0.25	0.28	0.40	0.47	0.52
Knee height [m]	0.28	0.35	0.47	0.54	0.59
Weight [kg]	14.5	23.0	49.8	75.7	101.1

Table 1: Anthropometry parameters of different body sizes

- the models accurately predict the global kinematics;
- the models accurately predict the impact points on the vehicle, especially for the head;
- the models can reasonably predict the occurrence of fractures in the upper and lower legs during the impact between the pedestrian and the vehicle;
- the models can predict the signal shape and trends of the head, chest and pelvis accelerations and the bumper forces.

The validated average male model was scaled towards a 3 year old child, 6 year old child, small female, and large male model (see Figure 3). The anthropometries of the small female and large male pedestrian models were also based on the RAMSIS database. The anthropometries of the 3 and 6 year old child were based on the specification of the Q child dummies. The global anthropometry specifications are given in Table 1.

The scaling of the pedestrian models was performed using the MADYMO/Scaler module (HAPPEE et al., 1998). Different scaling factors were specified for x-, y-, and z-dimensions and for different body parts to adapt the model geometry to the desired anthropometry. In addition to the geometry other model parameters were scaled.

As the pedestrian models are based on rigid body techniques the main advantages of this kind of models are the low computational costs, robustness and accurate predictions of kinematics. Therefore the model can be applied in studies involving a large number of runs, like stochastic simulations, for instance to determine ranges of impact conditions (e.g. head impact speed, head impact angle) for subsystem tests.

Typical Model Applications

A typical application is the evaluation of the pedestrian protection of the car front as for instance was done by HAPPEE and WISMANS (1999). HAPPEE and WISMANS first modelled and evaluated a production vehicle in MADYMO. Modifications were introduced such that all injury values were below 80% of the applicable tolerance values according to the EEVC test procedures (EEVC, 1998). Based on this optimised vehicle model, various vehicle models with markedly differing shapes were developed. As a next step, the 50th percentile male, a 5th percentile female and 3 and 6 year old child pedestrian models were applied to simulate lateral impact with the different vehicle models. From the simulations trends in injury reduction over the different vehicle models and over the various body sizes were identified.

As the pedestrian model can be scaled towards any desired body size, accident reconstruction is another typical application. Already a number of studies exist where the MADYMO pedestrian models are used in accident reconstruction simulations. COLEY et al. (2001) used an earlier version of the pedestrian model to reconstruct a real-world accident with a scaled version of the 5th percentile female pedestrian model. The performance of the pedestrian model was evaluated and afterwards the model was applied to reconstruct a fatal accident using a detailed vehicle model. Firstly the impact points between the pedestrian and the vehicle were matched and secondly the injury pattern was assessed by relating the injury value to an AIS level. In addition, further impact scenarios were explored to assess the ‘injury variation’ based on vehicle stiffness, initial pedestrian posture and position.

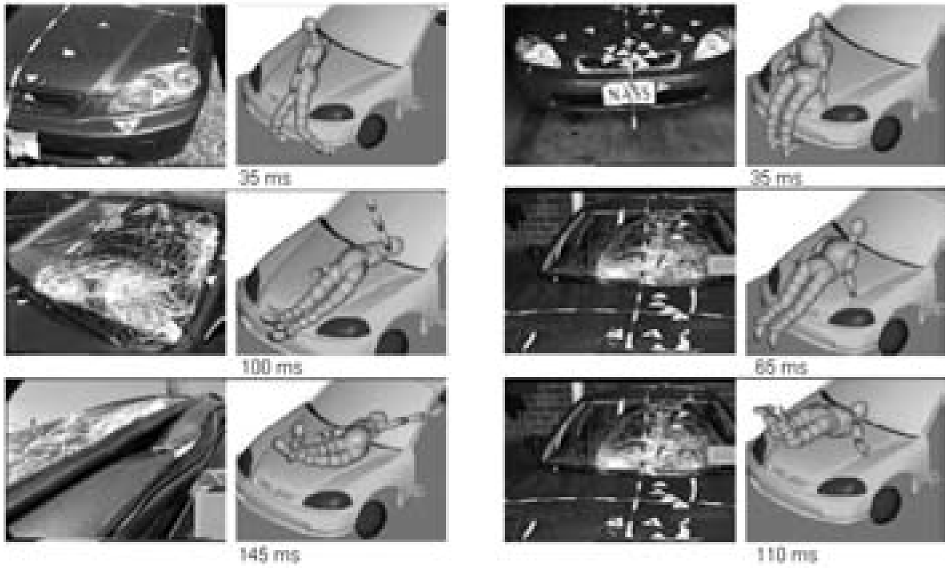


Figure 4: Comparison of the marks on the case vehicles with the contact locations in the MADYMO simulations (source: van ROOIJ et al., 2003)

In GLATIN et al. (2002) the focus was more on the throw distance of the pedestrian. In his study, GLATIN found an accurate match of throw distances between the simulations and the real-world data.

In 2004 STRZELETZ et al. compared the accident reconstruction simulations with the pedestrian models in MADYMO with several other numerical and experimental methods to further analyse pedestrian accidents. In his study STRZELETZ concluded that the accident reconstruction simulations in MADYMO do provide valuable information on the pedestrian model kinematics and the impact locations on the vehicle. As most parameters relevant in the accident are defined explicitly, the simulations were well suited to study the influence of differences in the initial conditions and the importance of different input parameters.

Van ROOIJ et al. (2003) developed and validated a vehicle model of a small family car using subsystems. He applied the developed vehicle model together with pedestrian models to reconstruct two pedestrian accident cases from the PCDS database (CHIDESTER et al., 2001). Case 1 was a non-fatal accident where a male (standing height: 1.75m; body weight: 79kg) was impacted with about 69km/h. Case 2 was a fatal accident where a female (standing height: 1.65m; body weight: 105kg) was impacted with 55km/h. A braking of 0.7G was applied to the vehicle model based on tire marks. The pedestrian models were scaled towards the required anthropometry using the MADYMO/Scaler module. A variation study was performed with a number of parameters like vehicle velocity, initial position and posture of the pedestrian model. Contact points between the pedestrian and the vehicle were compared with the marks on the accident vehicle. Based on this comparison (see Figure 4), the most likely accident scenario was derived.

For the two most likely scenarios, the injury outcome from the accidents was compared with the injury predictors in the models. In case 1, the leg injury results matched the observed severe leg injury and for case 2, the neck loads (N_{ij}) matched the fatal atlanto-occipital fracture observed in the accident.

Currently the MADYMO pedestrian models are used in the EC project APROSYS, to reconstruct pedestrian-vehicle and cyclist-vehicle accidents. The main aim of these reconstructions is to determine the impacted areas of the vehicle and to determine the nature of the loading conditions on the body of the pedestrian and pedal cyclists, including the head.

Ongoing Model Developments

The pedestrian models presented in this paper are based on the rigid body techniques available in MADYMO. As mentioned, the main advantages of this kind of models are the low computational costs,

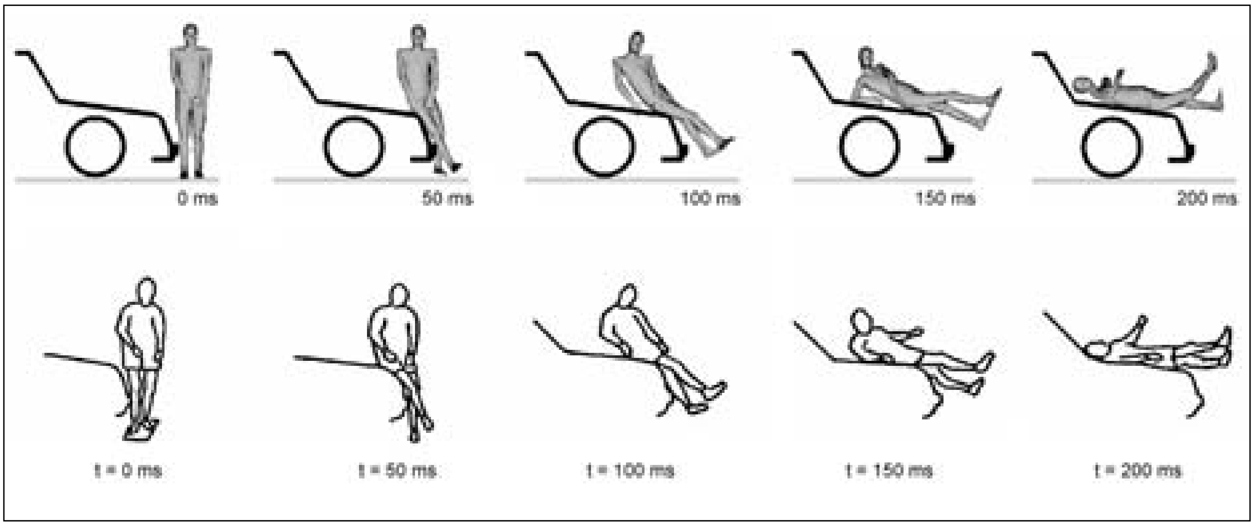


Figure 5: The kinematics of the facet pedestrian model in a 25 km/h impact and the corresponding test result as published by ISHIKAWA (1993)

robustness and accurate predictions of kinematics. Since ellipsoids were used to represent the geometry of human and vehicle, the prediction of the contact interaction is largely simplified.

A more advanced modelling technique is used for the MADYMO facet human model which can be seen in Figure 5. In this model the articulations are modelled with rigid body techniques and the skin with an so-called arbitrary surface. The model contains a more realistic spine and neck and a more detailed geometrical representation of the human body, but has limited capabilities to predict deformations. The model has been developed and validated for occupant impact simulations (LANGE et al., 2005). Due to its biofidelic set-up and the more accurate geometry description compared to the ellipsoid pedestrian models, this model is currently evaluated for its suitability for pedestrian impact simulation. As a first validation, several pedestrian tests published by ISHIKAWA et al. (1993) have been simulated. Figure 5 shows the kinematics of the average male pedestrian model in a 25km/h impact and the corresponding test result. As can be seen, the pedestrian kinematics correspond well with the pedestrian kinematics obtained in the test and also the impact locations between the pedestrian and the vehicle correspond well.

Additionally, the finite element (FE) technique enables prediction of detailed contact interactions and resulting deformations in structures with complex geometries. Recently, the FE human model developed in the EC project HUMOS 2 was adapted to a standing model and evaluated for lateral pedestrian impact (VEZIN and VERRIEST, 2005). Such a FE model enables more detailed analyses of the injury biomechanics associated with pedestrian impacts, such as bending and fracture of the bones and rupture of the ligaments. However, the main disadvantage of the FE approach is the much higher computational cost compared to rigid body. Furthermore critical stability issues are observed in soft tissue compression, which as yet prohibit routinely usage of such full FE human models.

One way to circumvent these limitations is to combine rigid body and FE techniques in one model. In this way an optimal combination of computational speed and accuracy can be obtained. A valuable combination could for instance be a rigid body pedestrian model combined with a FE model of the impacted leg. Such a model could provide a detailed insight in the leg injuries obtained, and as the remainder of the body is modelled with rigid body techniques, the computation time is still acceptable.

Discussion

As shown in this paper, the developed pedestrian models are used in a number of studies to reconstruct pedestrian-vehicle accidents. From these accident reconstruction studies it was concluded that throw distances of the pedestrian and, similar to the results of the validation, impact locations on the vehicle match fairly accurate with the experimental results and reconstructed accidents. This indicates a correct kinematic response of the pedestrian models. As such, accident reconstruction simulations help to obtain more details on specific accident cases and to provide an increased understanding of the sequence of events in the car-pedestrian impact. From the validation study it was concluded that the pedestrian models can reasonably predict the occurrence of fractures in the legs during the impact and that the models can predict trends in other injury parameters. This is supported by the findings of van ROOIJ et al. (2003), but more accident reconstructions of well documented cases are needed to further evaluate the predictive injury capability of human models, such as in LONGHITANO et al. (2005).

If a large number of accidents is reconstructed using similar methods as described above, such studies could lead to an improved validation of the human pedestrian models. This is thought to be valuable especially for specific populations as children and elderly pedestrians, where body tissue and bone fracture properties vary significantly from the 50^{th} percentile due to the age effects. For children, where neither body properties nor tolerance values are known, scaled human-body models can be used as a start and further modified based on the known differences between children, mid-aged adults and elderly people. As a first step in this method, LIU developed child pedestrian models and used the models to reconstruct two real world accidents using the accident data from in-dept accident investigations (LIU and YANG, 2002). In this study, it was concluded that the overall trajectories of the child models and vehicles and the head impact locations did correspond well with the accident data and the results indicated an acceptable correlation with the real-world injuries.

Besides the availability of a large number of accidents cases, such accident reconstruction studies for validation can only be performed if the cases are well documented and the reconstruction simulations are performed with a vehicle model that accurately matches the detailed geometry and the stiffness. Both parameters will have a significant influence on the model's response. Also the anthropometry of the pedestrian involved in the crash has a significant influence on the pedestrian kinematics in a pedestrian-vehicle impact. Therefore, the anthropometry has to be matched accurately by the pedestrian model which can be obtained using the MADYMO/Scaler module.

Conclusion

The MADYMO human pedestrian models have been verified using a range of full pedestrian-vehicle impact tests with a large range in body sizes. The models are available in number of body sizes ranging from a 3 year old child to a large male. In addition a scalable version has been developed.

The models are suitable as a tool for the reconstruction of pedestrian-vehicle accidents. The accident reconstruction studies described in this paper have shown that the simulations with the pedestrian models provide an improved understanding of the reconstructed accidents. Pedestrian kinematics, impact locations and pedestrian throw distances resulting from the simulations can be matched accurately with the accident observations. Provided that a large number of well documented pedestrian accidents could be reconstructed, this can even lead to an improved validation of the pedestrian models. This is thought to be especially valuable for specific population groups like children were currently sufficient data for validation is lacking.

Ongoing developments include a so-called facet pedestrian model with a more accurate geometry description and a more humanlike spine and neck and a full FE model allowing more detailed injury analysis.

Acknowledgements

The authors want to acknowledge J.B. REGNIER for his contribution to the validation of the facet pedestrian model. In addition, as information from a number of studies is used, the authors would like to thank the authors of those publications for sharing their information.

References

G. COLEY, R. LANGE, P. de OLIVEIRA, C. de NEAL-STURGESS, R HAPPEE: Pedestrian Human Body Validation Using Detailed Real-World Accidents, Proceedings of the IRCOBI Conference, 2001

A. CHIDESTER, R. ISENBERG: Final Report – The Pedestrian Crash Data Study, Proceedings of the 17th International Conference on the Enhanced Safety of Vehicles, Amsterdam, The Netherlands, 2001

European Enhanced Vehicle Safety Committee (EEVC): Working Group 17 report – Improved test methods to evaluate pedestrian protection afforded by passenger cars, 1998

N.N. GLATIN, M. LE, G. BLUNDELL, B. BROWN, B. ALLAN-STUBBS: Results of a Design of Experiments simulation of real world pedestrian vehicle accidents, Presented at the 9th international MADYMO user conference, Como, 2002

R. HAPPEE, R. HAASTER, L. van ROOIJ, L. MICHAELSEN, R. HOFFMANN: Optimisation of vehicle passive safety for occupants with varying anthropometry, Proceedings of the 16th International Conference on the Enhanced Safety of Vehicles, Canada, 1998

R. HAPPEE, J. WISMANS: Pedestrian protection full-body simulations, dummy validation, Proceedings of the VDA Technical Congress, Frankfurt, 1999

J. van HOOF, R. de LANGE, J. WISMANS: Improving Pedestrian Safety Using Numerical Human Models, Proceedings of the 47th Stapp Car Crash Conference, 2003

H. ISHIKAWA, J. KAJZER, G. SCHROEDER: Computer Simulation of Impact Response of the Human Body in Car-Pedestrian Accidents, Proceedings of the 37th Stapp Car Crash Conference, 1993

J. KAJZER, C. CAVALLERO, S. GHANOUCHI, J. BONNOIT, A. GHORBEL: Response of the Knee Joint in Lateral Impact: Effect of Shearing Loads, Proceedings of the IRCOBI Conference (pp. 293-304), 1990

K. KAJZER, C. CAVALLERO, J. BONNOIT, A. MORJANE, S. GHANOUCHI: Response of the Knee Joint in Lateral Impact: Effect of Bending Moment, Proceedings of the IRCOBI Conference (pp. 105-116), 1993

R. de LANGE, R. HAPPEE, J.K. YANG, X. LIU: Development and validation of full body human pedestrian models, TNO Automotive, The Netherlands, 2001

R. de LANGE, L. van ROOIJ, J. WISMANS: Objective Evaluation of a Human Model for Frontal to Lateral Impact, Proceedings of the 49th Stapp Car Crash Conference, 2005

X.J. LIU, J.K. YANG: Development of Child Pedestrian Mathematical Models and Evaluation with Accident Reconstruction, Journal of Traffic Injury Prevention, Volume 3 (pp. 321-329), 2002

D. LONGHITANO, C. BURKE, J. BEAN, D. WATTS, S. FAKHRY, M. MEISSNER, J. IVARSSON, C. SHERWOOD, J. CRANDALL, Y. TAKAHASHI, Y. KADOTANI, R. HITCHCOCK, Y. KINOSHITA: Application of the CIREN methodology of the study of pedestrian crash injuries, Proceedings of the 19th International Conference on the Enhanced Safety of Vehicles, Washington, U.S.A., 2005

M. MacKAY: Folklore and Science in Traffic Safety: Some New Directions, Injury Prevention and Control, London, Taylor & Francis, (pp. 89-98), 2000

D. OTTE, T. POHLEMANN: Analysis and Load Assessment of Secondary Impact to Adult Pedestrians after Car Collisions on Roads, Proceedings of the 17th International Conference on the Enhanced Safety of Vehicles, 2001

A. SEIDL: Das Menschmodel RAMSIS: Analyse, Synthese und Simulation dreidimensionaler Körperhaltungen des Menschen, PhD dissertation, Technical University of Munich, Germany, 1994

R. STRZELETZ, K. KÜHN, A. KAMPA: Vergleichende Bewertung von Simulation und Experiment am Beispiel des Fußgänger-Fahrzeug-Unfalls, EVU Conference, Prague, 2004

L. van ROOIJ, K. BHALLA, M. MEISSNER, J. IVARSSON, J. CRANDALL, D. LONGHITANO, Y. TAKAHASHI, Y. DOKKO, Y. KIKUCHI: Pedestrian crash reconstruction using multi-body modeling with geometrically detailed, validated vehicle models and advanced pedestrian injury criteria, Proceedings of the 18th International Conference on the Enhanced Safety of Vehicles, 2003

P. VEZIN, J.P. VERRIEST: Development of a set of numerical human models for safety, Proceedings of the 19th International

Conference on the Enhanced Safety of Vehicles, Washington, U.S.A., 2005

World Bank Group Road Safety: http://www.worldbank.org/html/fpd/transport/roads/safety.htm (accessed February 20th, 2003), 2003

H. YAMADA: Strength of biological materials, Baltimore, Maryland Williams and Wilkins, 1973

M. Jänsch, D. Otte, C. Krettek
Accident Research Unit and Trauma Department, Hannover Medical School

Fatal Traffic Accidents in Lower Saxony– A New Approach to Accident Sampling and Analysis of Accident Causes and Configurations

Abstract

In the context of this study, different data sources for accident research were examined regarding their possible data access and evaluated concerning the individual quality and extent of the data. Analyses of accidents require detailed and comprehensive information in particular concerning vehicle damages, injury patterns and descriptions of the accident sequence. The police documentation supplies the basic accident statistics and is amended in the context of the forensic treatment by further information, e.g. by medical and technical appraisals and witness questionings.

As a new approach to the data acquisition for the analysis of fatal traffic accidents, the information was made usable which was collected by the police and by the investigations of the public prosecutor. The best strategy for obtaining reliable, extensive and complete data consists of combining the information from these two sources: the very complete, but elementary statistic data of the Niedersächsisches Landesamt für Statistik (Lower Saxony State Authority of Statistics), based on the police documentation as well as the very extensive accident information resulting from the investigation documentation of the public prosecutor after conclusion of the procedure, the so-called Court Records.

Of all 715 fatal traffic accidents, which happened in the year 2003 in the German State of Lower Saxony, 238 cases were selected by means of a statistically coincidental selective procedure based on a statistically representative manner (every third accident). These cases cover the investigation documents of the 11 responsible public prosecutor's offices, which were requested and evaluated while preserving the data security. Of the 238 cases 202 cases were available, which were individually coded and stored in a data base using 160 variables. Thus a data base of a sample of representative data for fatal accidents in Lower Saxony was set up. The data base contains extensive information concerning general accident data (35 variables), concerning road and road surface data (30 variables), concerning vehicle-specific data (68 variables) as well as concerning personal and injury data (27 variables).

Introduction and Purpose

Traffic accident data of a country or a state, which are relevant for the research of accidents, can be collected from a number of different sources. The standard way of accident data acquisition is to use primary police documents in form of the police report. The research report of the BASt from the year 1976 [1] indicates that there are about 50 items of information available, which have changed over the years, and the number of data collected has rather decreased. Further possibilities exist in the data collection at the site of the accident by scientific teams and by the evaluation of insurance documents, for example of the GDV. Alternatively a new approach for the procurement of accident-relevant data was selected: For the year 2003 traffic accidents in Lower Saxony with fatal outcome were examined on the basis of information from the investigation documents of the public prosecutor's offices and collected in a data base. The Niedersächsisches Landesamt für Statistik (Lower Saxony State Authority of Statistics) (NLS) supplies very complete data records containing all the basic data to the extent of the police accident report. In contrast, the documents of the public prosecutor's offices frequently contain quite profound and detailed data. For getting hold of the investigation documents of the public prosecutor, it was necessary to figure out the register number of the public prosecutor's office by using the police documentation.

The Data of the Niedersächsisches Landesamt für Statistik (Lower Saxony State Authority of Statistics)

The first source of accident data concerning traffic accidents with fatal consequences in Lower Saxony is the data set of the Niedersächsisches Landesamt für Statistik, NLS. The NLS collects data concerning every traffic accident in Lower Saxony which is recorded by the police and where as a consequence of the accident there is at least one tow away vehicle or which resulted in the injury of one or more persons. A defined data record is conveyed to the Federal Statistical Office from the data bases of the states of the Federal Republic, in order to achieve an overview of the total situation in Germany.

The basis of the NLS data base are police statistics based on police reports (level 1). Therefore the data records of the NLS are very similar to those of the police data bases existing at police headquarters. Additionally, here however further data are supplemented (in particular vehicle-specific data) from other national data bases (e.g. the Kraftfahrt-Bundesamt [Federal Motor Transport Authority]) (level 2).

The NLS recorded data concerning 715 traffic accidents with fatalities in Lower Saxony in the year 2003. For each person involved in an accident the NLS data record consists of 108 different variables. This results in the fact that an accident can have several data records according to the number of involved persons. The structure of the NLS data records can be divided into 4 different categories:

1. Accident-specific data. In this category data relating to 57 variables in view of the accident scene, date and time as well as the kind of the accident are collected.

2. Data referring to the road user. Here the focus is on the data of the road user (e.g. the driver of a vehicle, a pedestrian or vehicle-specific data). The 34 variables of this category refer both to personal data and the age, the nationality of a road user or the cause of accident as well as to technical data of the vehicle like e.g. motor vehicle type, load, engine data etc.

3. Injured passengers. In this category, 10 variables, concerning the age, sex and the injury severity of up to 10 passengers per vehicle are indicated.

4. Data processing characteristics. The data in this category are used internally for data processing purposes. These 7 variables are not relevant here.

The Investigation Documents of the Public Prosecutor's Offices as a Data Source

With each traffic accident with fatal consequences the appropriate public prosecutor's office is informed by the investigating police department. The area of Lower Saxony is divided into 11 responsible public prosecutor's offices. Therefore the appropriate public prosecutor's office investigates the accident dependent on the location. Figure 1 shows the competency areas of the 11 public prosecutor's offices in Lower Saxony.

In the context of the public prosecutor's investigation by the corresponding public prosecutor's office an investigation document concerning the traffic accident is established on the basis of the police report. For this reason an investigation document exists at the corresponding public prosecutor's office for every one of the 715 fatal traffic accidents in Lower Saxony in the year 2003. These investigation documents are usually very extensive data sources, which also offer very extensive data for the research of accidents. Since the public prosecutor's offices examine the traffic accidents based on a legal background, the investigation documents can contain a variety of different documents and sources of information (level 3), which may, however, be equally missing in other investigation documents. Among the most frequent documents and sources of information which were gathered in the investigation

Figure 1: Competency areas of the 11 public prosecutor's offices in Lower Saxony

documents concerning a fatal traffic accident belong:

- traffic accident notification of the police,
- traffic accident investigation report of the police,
- photo report of the police,
- death certificate,
- testimonies,
- damage or accident reconstruction appraisals,
- autopsy report or medical injury opinion.

Usable information from the investigation documents of the public prosecutor's office

The data, which can be found in the investigation documents can be subdivided into the following four categories: data of the surrounding area, vehicle data, data concerning the persons and injury data.

The data of the surrounding area contain information concerning the site of the accident, the climatic conditions, the cause of accident etc. This is normally also supplemented by photos of the accident site. In some cases, an expertise of an accident reconstruction is present, which supplies further specific information.

The vehicle-specific data to be found in the investigation documents are fundamental information about the vehicles, the technical condition of the vehicles and the damage to the vehicles. This usually includes also photos of the vehicles. In some cases also an expertise of the damage is present.

The personal data from the investigation documents supply specific data like age, sex, occupation, driving license etc. Rather fundamental information concerning injuries is found in the police reports or death certificates. This information is present in nearly all investigation documents. As very extensive source of injury information some documents additionally contain autopsy reports, injury appraisals and/or photos of injuries as well as of vehicle deformations.

Data Acquisition Methodology

In order to obtain as representative accident data as possible for Lower Saxony regarding the traffic accidents with fatal consequences, there is also the possibility of taking a statistically representative sample aside from the use of all individual documents. Examining all fatal traffic accidents with over 700 investigation documents of the public prosecutor's offices (total data collection) would have entailed an excessive personnel expenditure. For this reason, a representative selection was taken from investigation documents of the Public Prosecutor. In order to ensure that all judicial procedures for the investigation documents were already concluded and therefore the availability of the documents was given, the year 2003 was selected for the collection year.

The number of approx. 200 investigation documents constitutes a sufficient number of investigation documents for statistically representative purposes, which could be examined at a justifiable personnel expenditure.

In order to be able to make representative statements from the data of the public prosecutor's investigation documents for Lower Saxony, a sampling method was used for the selection of the documents, where the sub-sample was formed from all accidents with fatal consequences. Initially for this purpose the basic data concerning all traffic accidents with fatal consequences in the year 2003 were transmitted by the NLS. These data contain:

District, county, municipality, accident day, accident month, accident year, weekday, accident time – hour, accident time – minute, number of participants, number of fatalities, number of severely injured persons, number of slightly injured persons, type of accident, characteristics of the accident scene, special features of the accident scene, set of lights, speed limit, lighting conditions, road conditions, impact on obstacles at the roadside, effect of alcohol, car not road-worthy, general provisional causes, local position, accident category, type of accident, road class, road number, km specification, driving direction, road code, causes of accident – 1. Cause, causes of accident – 2. Cause, causes of accident – 3. Cause, leaving the scene of the accident, date of birth, age in years, resident aliens in Germany, nationality plate, license plate administrative district, number of vehicle occupants, accident consequences of involved persons, 1st passenger: inj./sex, 1st passenger: age in years, 2nd passenger: inj./sex, 2nd passenger: age in years ... 10th passenger: inj./sex, 10th passenger: age in years, blood alcohol concentration, required driving license exists, date of issue of license: month, date of issue of license: year, type code: vehicle manufacturer, type code: basic type, type code: type execution, type code: check digit, vehicle type, body style, engine performance in kW, capacity in ccm, max. speed, number of axles, propelled axles, curb weight in kg, permissible total weight, registration date, label for additional expert's opinion, hazardous materials hazard category, hazardous materials digit/letter, no. of the exemption regulation, release of hazardous materials, amount of damages to property, registration date in years.

By means of a statistic random principle, every third accident was selected and the appropriate court record was procured from the 11 different public prosecutor's offices. From the complete list of the NLS with 715 deadly traffic accidents from the year 2003, n=238 of cases were selected and were to be examined.

At the different interfaces of the file access (police, public prosecutor's office) the data record structure was described in order to be able to later discuss the possibilities of the use regarding type, scope and quality of the information.

In order to be able to refer to the 238 selected investigation documents of the 11 responsible public prosecutor's offices, first some foundations had to be laid. Since the investigation documents naturally contain personal information and thus are subject to the protection of privacy, all members of the investigation team who handled the investigation documents were obliged to sign a confidentiality agreement. This is a confidentiality agreement according to the Verpflichtungsgesetz (Law on the Commitment of Persons to Secrecy) dated March 2nd, 1974 (BGBl. I S. 469).

In the second step it was necessary to request the public prosecutor investigation documents from responsible public prosecutor's offices using the appropriate reference number. 202 investigation documents could be made accessible by the public prosecutor's offices. All 202 requested investigation documents arrived within a relatively small period of time and had to be returned to the appropriate public prosecutor's offices after a relatively short retention period. For this reason it was necessary to first digitize the investigation documents using scanners and then to store the copies temporarily. These digital copies were then used for coding and entering of the accident-specific data after they were made anonymous regarding personal data.

Data Structure

The data both from the public prosecutor's investigation documents and from the tables of the NLS were combined in a data base. This is a data base that was adapted particularly to the information content of the investigation documents and the data of the NLS. For each case the data in 160 different variables and text fields were coded and stored in the data base. Since the 202 recorded fatal accidents constitute a representative selection of all 715 fatal accidents in Lower Saxony in the year 2003, a representative data base extending beyond the statistic level was created for accidents with fatal consequences in Lower Saxony. The created data base is called FALS (Fatal Accidents Lower Saxony). The structure of this data base with 160 variables per case can be outlined as follows in Figure 2. A list of the variables can be found in table 1 in the Annex.

For the 202 fatal traffic accidents from the year 2003 in Lower Saxony recorded in the data base, the data of 337 traffic participants involved in an

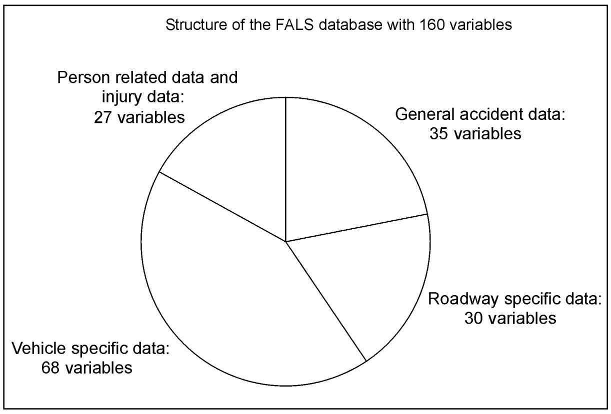


Figure 2: Structure of the data base FALS containing fatal accidents in Lower Saxony

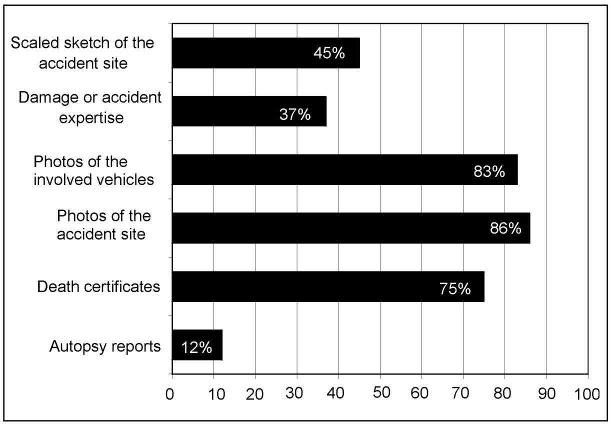


Figure 3: Percentage of the occurrence of information sources in public prosecutor's investigation documents

accident and of 482 participating persons were coded. Of these persons 225 persons (47%) were fatally injured, 67 persons (14%) were severely injured, 75 persons (16%) were slightly injured and 115 persons (47%) remained unhurt.

The public prosecutor's investigation documents can contain a multiplicity of different sources of information. Figure 3 shows an overview of the availability of these sources of information in the investigation documents.

Photos of the accident site and of the vehicles were present in over 83% of the cases. Scaled sketches of the accident place however existed only in 45% of the cases and technical expert's opinions in only 37%. Autopsy reports only existed in 12% of the cases. This surely constitutes a special situation in Lower Saxony. It was reported that for the State of Bavaria for instance in about 80% of the cases an autopsy is performed [2]. In only two cases (1%) there was also a forensic expert's report to answer the question of the use of a belt.

Classification of accident constellations

In the course of the coding of the selected sample of 202 accidents, the accident type classification of the ISK (Institut für Straßenverkehr Köln – Institute for Traffic Cologne) was applied. This provides an accident type classification in 7 main categories and subsequently into several sub-categories of the respective main categories. However when setting up the accident report, the police uses the classification into the 7 main categories only and not the more extensive classification into the various sub-categories by means of a 3-digit code. In the context of this study regarding the 202 court records the extensive, more detailed classification of the accident type code having 3 digits was used. From the sample of the 202 accidents it turned out that with 96 accidents 48% of all accidents were driving accidents. The second most frequent type of accident was the accident in longitudinal traffic at 15% (30 accidents), followed by turning/intersecting accidents at 12% (25 accidents), turning accidents at 10% (21 accidents) and crossing accidents at 9% (18 accidents). The accident types occurring least frequently were accidents by stationary traffic with only 2% (5 accidents) and other accidents, which could not be classified into the categories already mentioned, at 3%. Figure 4 shows the distribution of the accidents of the sample of 202 accidents classified according to accident types compared with the situation in all 715 deadly accidents in Lower Saxony in the year 2003. It shows that the sample exhibits a good representativeness regarding the classification into the 7 accident types. Slight deviations result from the fact that the

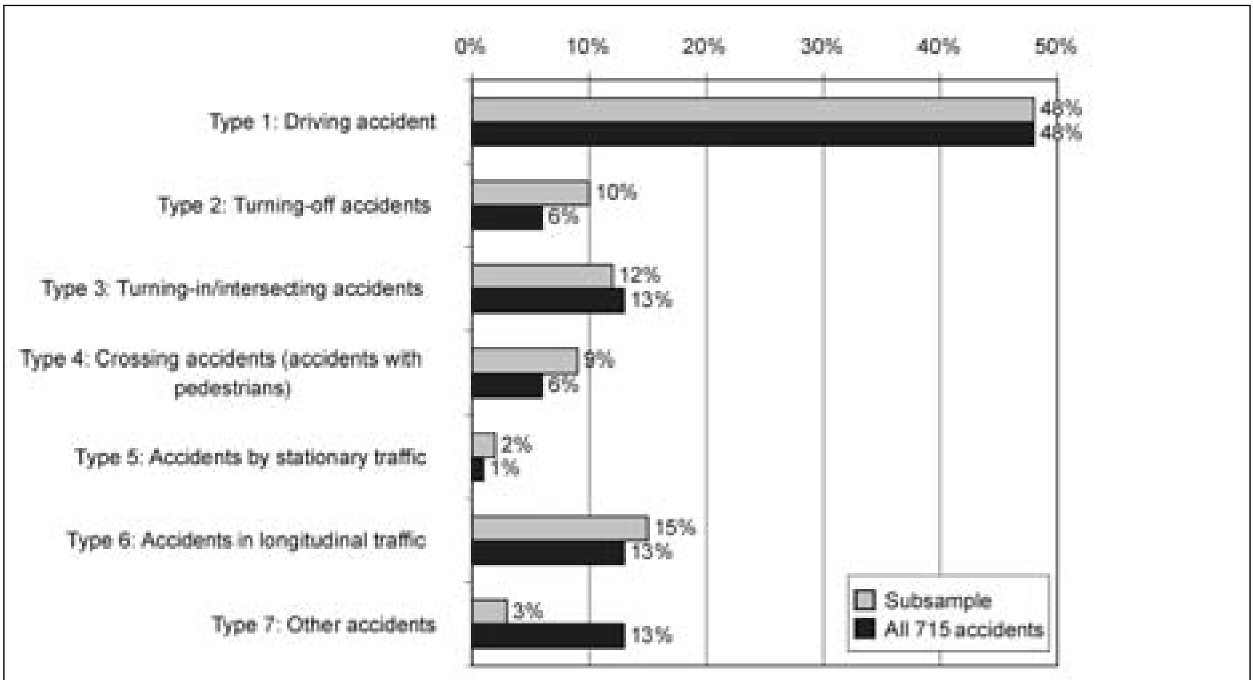


Figure 4: Distribution of the accidents into the 7 accident types. Indicated for all 715 fatal accidents in Lower Saxony in 2003 und for the random sample of 202 accidents

classification of the 715 accidents of the NLS was made by the police at an early stage, when possibly not all circumstances of the accident had been known. The classification of the 202 accidents from the sample, however, was based on the complete information content of the public prosecutor's investigation documents after the conclusion of the forensic procedure.

A detailed evaluation of these accident types in the sub-categories resulted in the following accident structure for the sample:

Driving accidents
Within the 96 driving accidents 60 accidents occurred in a curve. Left and right curves have a similarly high percentage. Of the remaining 36 driving accidents, 34 accidents occurred on straight roads and only 2 accidents in other situations.

Turning accidents
The largest share of the 21 turning accidents were accidents between a vehicle turning left and an on-coming vehicle (14 accidents). Five accidents were accidents between a vehicle turning left and a following vehicle.

Turning/intersecting accidents
Within this category the accidents were distributed predominantly on two sub-categories. 13 of the accidents happened due to conflicts between a vehicle required to wait and one coming from the left with the right of way. Of the remaining 12 accidents in this category 8 accidents happened due to conflicts between a vehicle required to wait and one coming from the right with the right of way and 4 accidents can be distributed to other sub-categories.

Accidents with pedestrians
Of the 18 accidents with pedestrians, 8 accidents occurred due to a conflict between a vehicle and a pedestrian crossing from the right side. Only 4 accidents occurred due to a conflict between a pedestrian coming from the left side and a vehicle. The remaining accidents with pedestrians can be distributed to other sub-categories.

Accidents in stationary traffic
3 of the 5 accidents in stationary traffic happened due to a conflict between a vehicle and a vehicle parking and/or being stationary in front.

Accidents in longitudinal traffic
The majority (13 accidents) of the 30 fatal accidents in longitudinal traffic fall into the sub-category "conflict between encountering vehicles". Another 5 accidents happened due to a conflict between a vehicle and a vehicle preceding it on the same lane. The remaining 12 accidents in this category can be distributed to approximately the same measure on the remaining sub-categories.

Other accidents
Of the 7 accidents not fitting into any of the preceding categories 5 accidents fall into the sub-category "accident by sudden physical inability of the road user".

Figure 5 shows the 10 most frequent types of fatal accidents in accordance with the detailed ISK classification with sub-categories.

It is obvious that the type of accident "driving accident in a curve" is the most frequent type of fatal accident at nearly 30%. The secondary most frequent type of accident is at nearly 17% the driving accident on a straight stretch of the road. The remaining 8 types of accidents lie relatively closely together at frequencies from 2.5% to 7%. Here, no clear order of the frequency of the occurrence can be given, as for only 202 accidents the statistic inaccuracy would be too great.

In order to take the specific characteristics and collision situations of the different road users into consideration, the most frequent type of accident for passenger car drivers, truck drivers, pedestrians, riders of motorbikes and for cyclists was determined (Figure 6). Of the sample containing 202 accidents 167 accidents involved a passenger car, with the most frequently occurring type of accident being a "driving accident in a curve" at 31%. Of the 39 accidents with truck participation the type "accident in longitudinal traffic with oncoming traffic" occurred most frequently at 15%. Of the 32 accidents with motorcycle participation within the sample, the type of accident "turning accident with oncoming traffic" was most frequently represented at 25%. Of the 20 accidents with bicycle involvement, the type "turning/intersecting accident with priority traffic from the left" occurred most frequently at 20%. In fatal accidents, in which pedestrians were involved (21 accidents), in 33% of all cases the most frequent type of accident turned out to be the "crossing accident with pedestrian from the right".

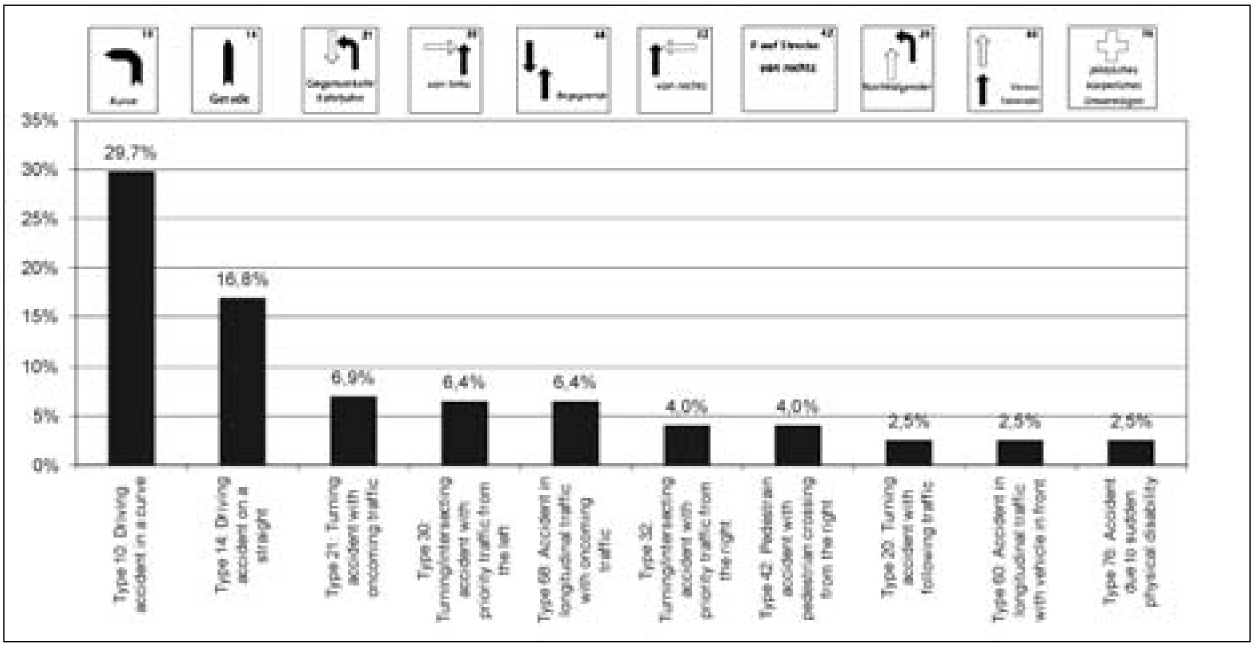


Figure 5: Representation of the 10 most frequent accident types according to the detailed classification

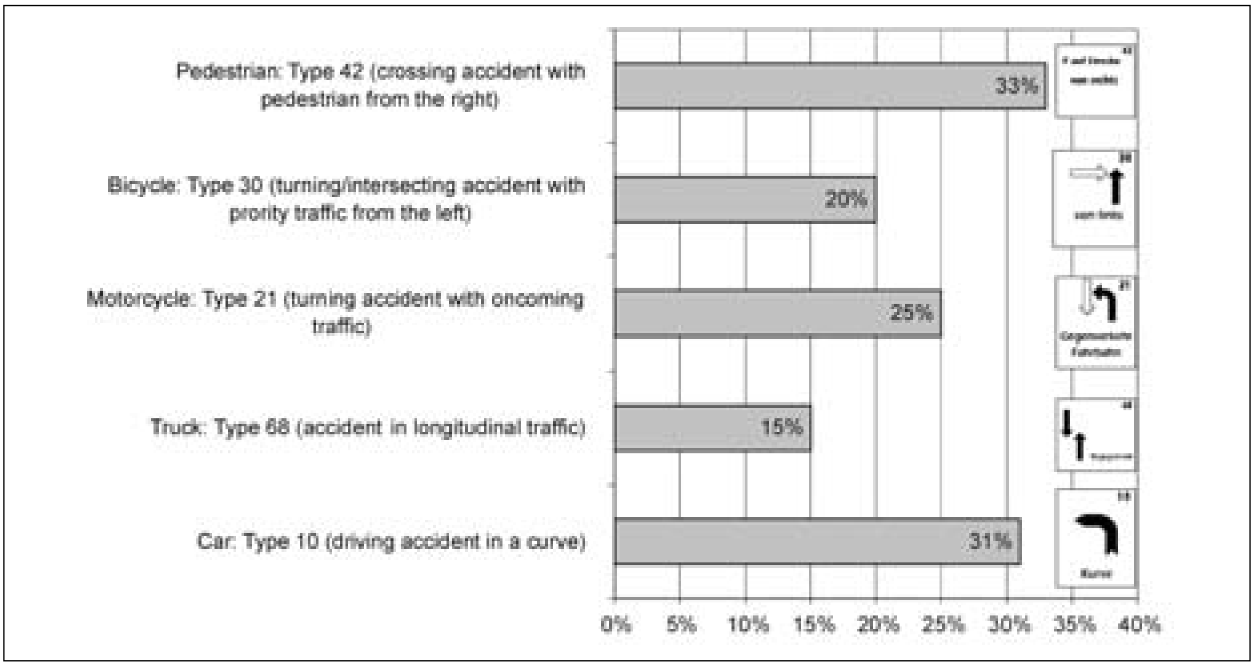


Figure 6: Proportion of the most frequent type of accident as a function of the motor vehicle type involved in a fatal accident

Evaluation of Representativity – Accident Structure and Injury Situation

The question regarding the representativity of the methodically collected information here by means of procedures of random sampling arises, so that in the following a selection of statistic evaluations was conducted, in order to also create a comparison of this sample to the known results of all accidents besides the comparison of accident and injury situations of killed road users in Lower Saxony. For this purpose most figures show the values from the table of the NLS (for all 715 fatal accidents in Lower Saxony 2003) as well as the values from the data base FALS with the data from the public prosecutor's files of inquiry (selection of 202 fatal accidents in Lower Saxony 2003). While the data from the NLS were frequently coded on site by the police, after the study of the files of inquiry the data were coded again, independently of the police coding. On the one hand the police may not have had access to all information (e.g. appraisals) at the time of coding and on the other hand some variables leave more room for different interpretations (e.g. lighting or road conditions). The larger deviations in some areas are possibly due to this fact.

1. Structure of fatal accidents in Lower Saxony

A reasonable accordance between the selected sample and all road users killed in Lower Saxony appears in the distribution of the characteristics: type of accident, kind of road and type of local area. With the detailedness of the available information of the sample cases even accident parameters such as collision speed could be determined.

As Figure 7 shows, according to the sample most fatal accidents in Lower Saxony occurred on federal highways and state highways at 30% and 29% in the year 2003. Significantly fewer fatal accidents occurred on the motorways in Lower Saxony at 8% and on the usually calm rural roads (10%). The percentages of the total group of fatalities showed almost identical values (±1%). This confirms the good representativity of the database of FALS and thus of the selective procedure.

Also Figure 8 giving the distribution of the fatal accidents depending on the local area shows the same data in the sample as in the total data collection, 79% of the accident victims occurred outside urban areas (total data collection 80%).

Due to the high proportion of passenger cars in traffic, in the sample 63% of the vehicles involved were passenger cars (65% in the total data collection) – Figure 9. Trucks were involved at only 15% (total data collection 14%) and motorcycles only at 9% (also 9% in the total data collection). Of the non-motorized road users, cyclists were involved in 6% and pedestrians in 7% (total data collection in each case 6%) of the cases.

Figure 10 shows the most frequently occurring kinds of fatal accidents. Leaving the carriageway (to the left or to the right) occurs in 43% of all accidents. The second most frequent kind of accident among the fatal accidents is a collision with an oncoming vehicle or with a crossing vehicle.

37% of the public prosecutor's files of inquiry from the sample (202 cases=100%) contain a technical

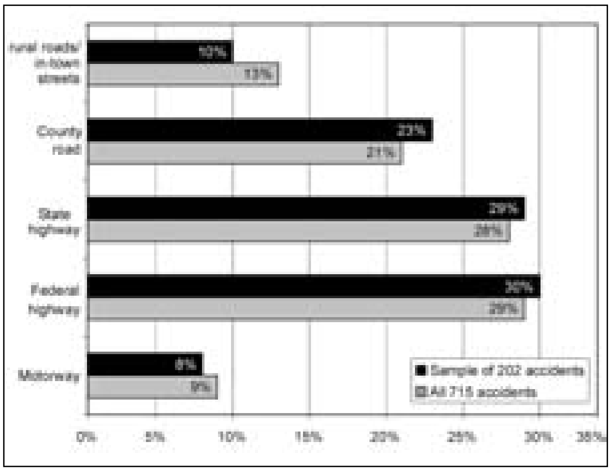


Figure 7: Distribution of the fatal accidents according to the type of road for the situation in Lower Saxony in 2003 (715 accidents) and for the selected 202 accidents

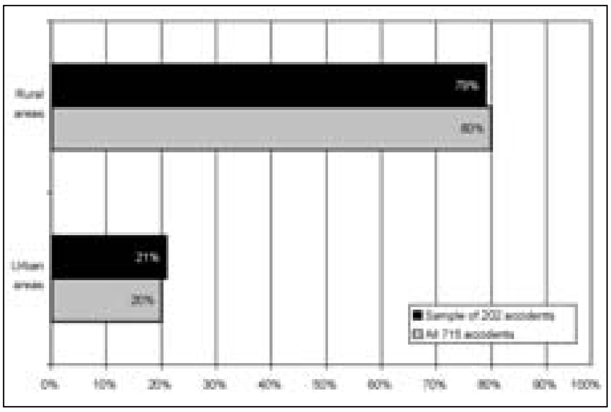


Figure 8: Distribution of the fatal accidents according to the local area in Lower Saxony in the year 2003 (715 accidents) and for the sample of the 202 accidents from the data base

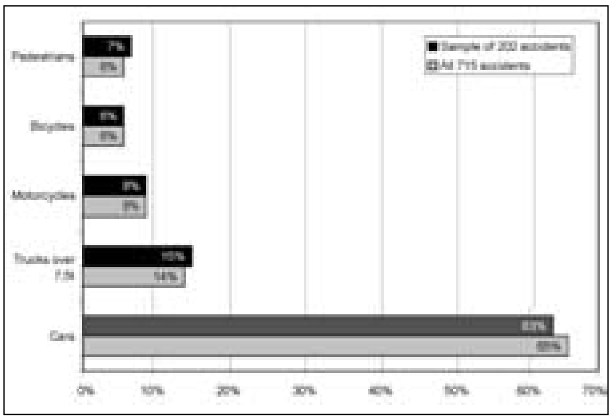


Figure 9: Distribution of the kind of the road users, who were involved in fatal accidents

expertise. In the context of these appraisals for 84 people involved in 53 traffic accidents a collision speed was determined by experts. Figures 11 and 12 show the distribution of the determined velocity

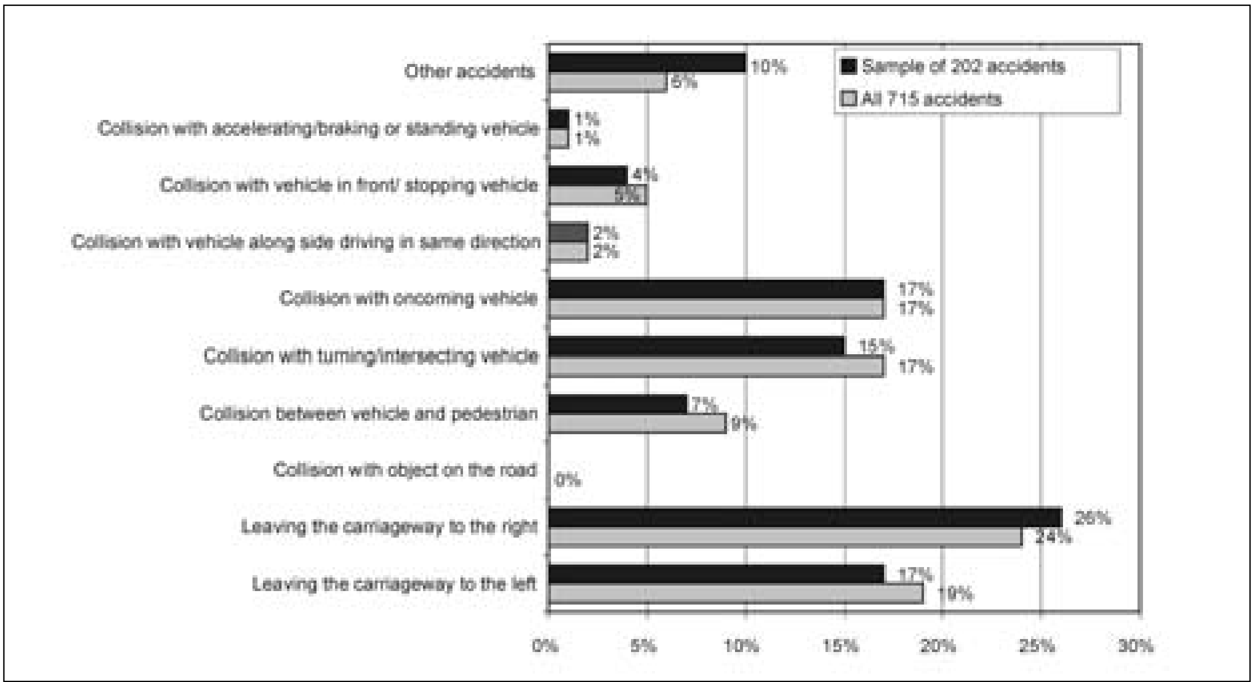


Figure 10: Distribution of the type of accident in all fatal accidents as well as in the accidents of the database from the public prosecutor's files of inquiry

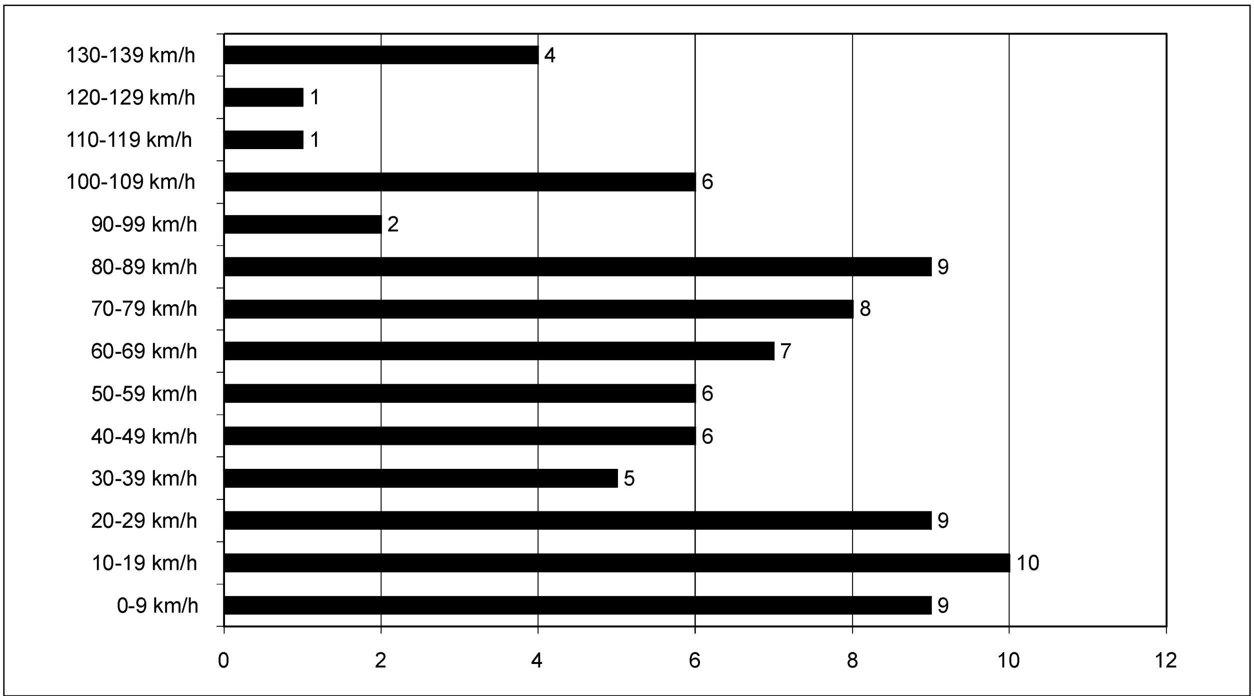


Figure 11: Distribution of the number of people involved in an accident on the collision speeds in fatal accidents with expert's opinions

values for the 84 people involved in accidents. It is obvious that the range up to a collision speed of 30km/h is most frequently represented. Within this range the accidents with pedestrian and cyclist occurred. Beyond 30km/h, the number of people involved in accidents increases with the corresponding collision speed up to a range of 90km/h, as higher collision speeds generally result in a greater injury severity. People involved in an accident with collision speeds of more than 80km/h are still relatively frequently found at approximately 25%. It is to be kept in mind that generally a speed-reducing condition preceded the collision, such as braking or swerving. The driving speeds at accident

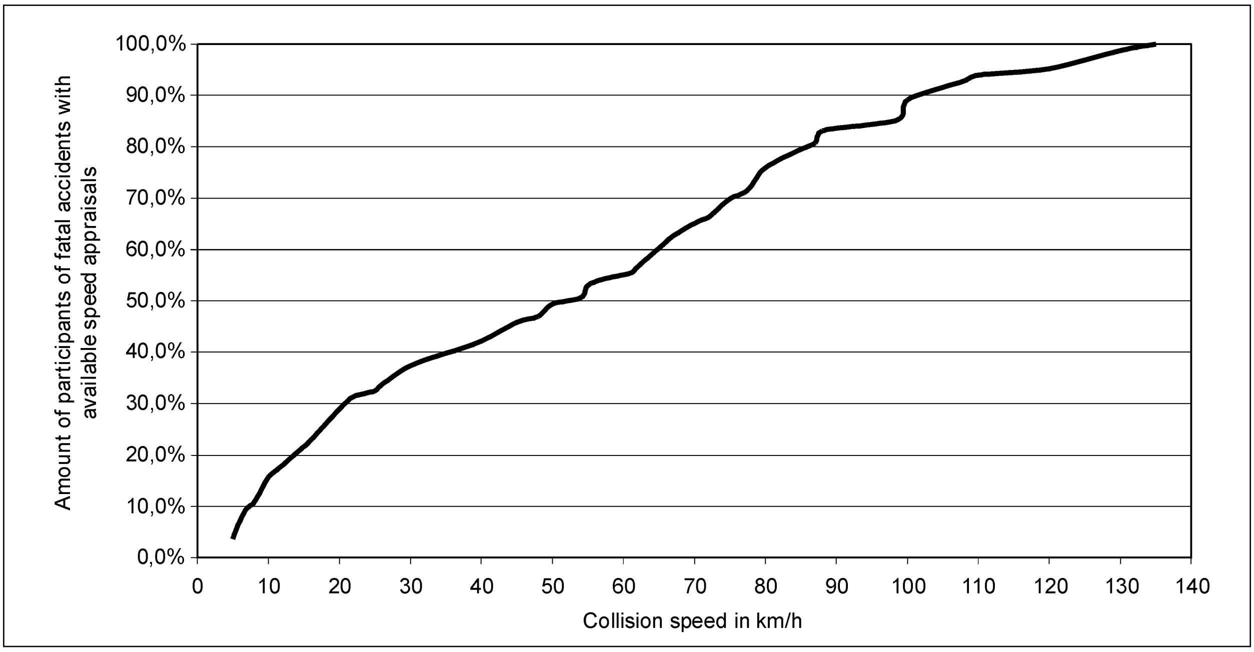


Figure 12: Number of persons involved in fatal accidents with speed appraisals as a function of the collision speed applied as cumulative incidence

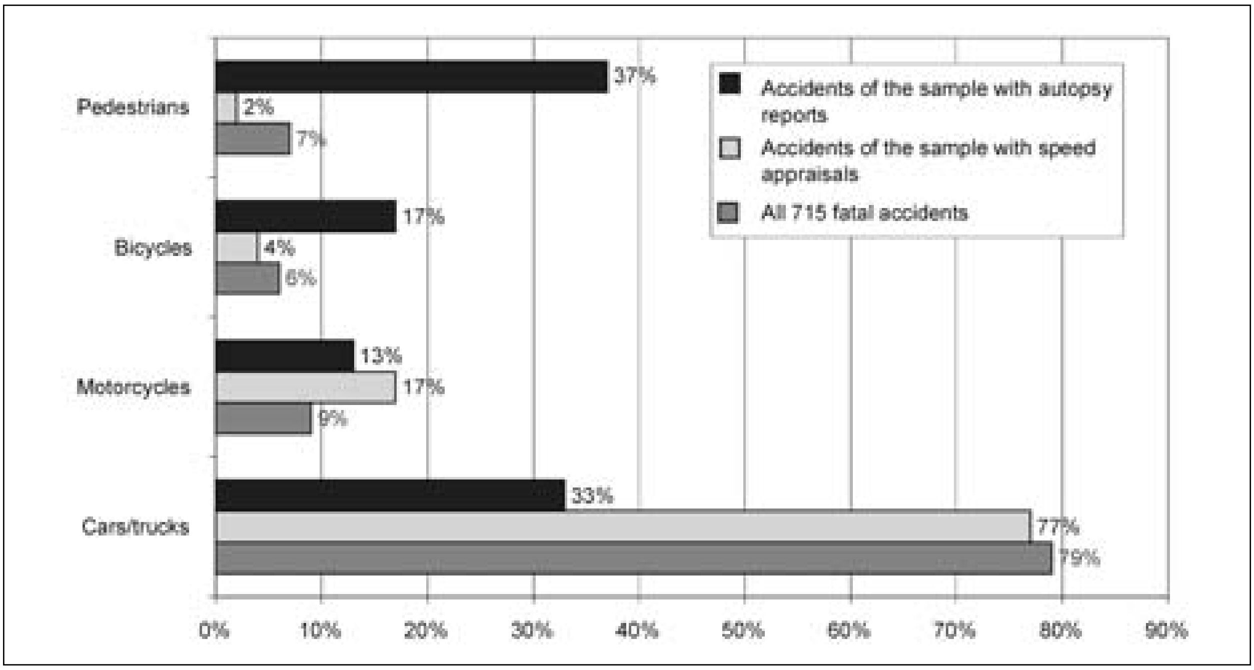


Figure 13: Distribution of the type of road user with all 715 fatal accidents in Lower Saxony in 2003 as well as in all accidents of the sample in which a speed appraisal is present and in all accidents of the sample in which an autopsy was performed

initiation usually exceed the corresponding collision speeds (Figure 11 and 12).

For the statistically representative significance of the represented distribution of the collision speeds (Figure 11 and 12) it is of importance that the speed appraisals which were ordered by the police and/or by the public prosecutor's office show a certain representativity regarding the total situation.

Figure 13 shows the distribution of the road users for all 715 fatal accidents in Lower Saxony compared to the sub-sample for all accidents with speed appraisals from the sample of 202 fatal accidents as well as for all accidents with autopsy reports from the sample. The proportional frequency of the participation of the 4 road user types pedestrians, cyclists, motorcycles and passenger car/truck is represented in each case.

Here the representativity of the cases where a technical appraisal with collision speeds is present is given, at least regarding cars/trucks and cyclists. The portion of the motorcycles with the speed appraisals at 17% is nearly twice as high as the total number of accidents that occurred (9%). Fatal accidents with pedestrians however are underrepresented at 2% of the cases as opposed to 7% of the total number of accidents that occurred. This is surprising, since it has been assumed that in fatal pedestrian accidents there would be a particular interest at the side of the public prosecutor to determine the speed by means of a technical appraisal. It seems to be greater however, if passengers in cars suffer from fatal consequences of accidents.

A relatively clear correlation of autopsy orders for certain groups of road users can be seen. At 37% of the autopsies the pedestrians are strongly over-represented, as their corresponding proportion in the 715 fatal accidents in Lower Saxony is 7%. The same applies to bicycle riders. While 17% of all traffic fatalities from the sample on whom an autopsy was performed were cyclists, these were involved only to 6% in fatal accidents. Autopsies were performed on 13% of the motor cyclists, whereas only 9% were involved in fatal accidents. A different picture is revealed when the road user is a passenger car/truck. Persons in this type of motor vehicle are involved in 79% of the fatal accidents in Lower Saxony. They were subject to autopsies only at 32% of the traffic fatalities that occur, however. Thus clearly a statistically representative analysis from autopsy data is not possible, autopsy protocols are often oriented at forensic criteria and provide a detailed description of the injuries. Of the selected sample of 202 fatal accidents in Lower Saxony in the year 2003, autopsies were performed on only 24 cases (12%).

2. Injury severity and injury pattern of fatal accidents in Lower Saxony

The injuries of the autopsy reports were coded in accordance with the "Abbreviated Injury Scale" AIS 2005, so that a statistic evaluation was possible. The distribution of the injury severity of all 278 coded injuries in accordance with the AIS classification is represented in Figure 14. AIS 1 corresponds to a slight injury, AIS 2 to a moderate injury, AIS 3 to a severe injury, AIS 4 to a serious injury, AIS 5 to a critical injury and AIS 6 to an injury not treatable at the time. The AIS value of 9 designates unknown injuries, which are represented at less than one per cent here.

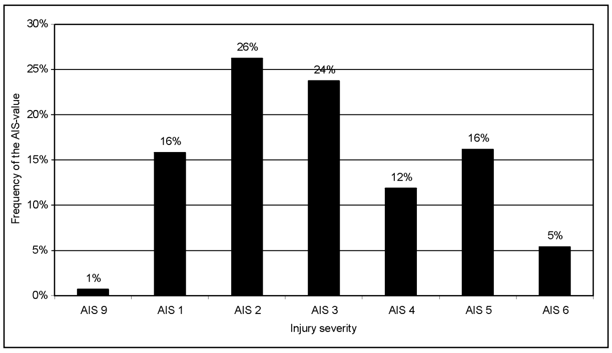


Figure 14: Distribution of injury severities in accordance with AIS covering all 278 injuries of the 24 traffic fatalities on whom autopsies were performed

It is shown that moderately severe injuries AIS 2 and AIS 3 occurred most frequently at around 25% each with the accident victims. However only 16% of the injuries were slight injuries (AIS 1). Of the severe injuries, which often led to fatality, 12% were AIS 4 as well as critical injuries (AIS 5) at 16% and AIS 6 (5%), altogether thus 21%, were particularly frequently represented.

In Figure 15, the distribution of the 159 heaviest injuries (all injuries starting from AIS 3) is represented according to the body regions. Additionally these injuries are sub-divided according to the injury severity into the categories AIS 3, AIS 4, AIS 5 and AIS 6. It is shown that head injuries are strongly represented within the 4 groups of the most severe injuries. There were virtually no injuries to the face or to the neck of AIS values of AIS 3 and more. Thorax and stomach injuries however occurred more frequently in all groups of AIS 3 and more, just like head injuries. Severe injuries to the spinal column are rare. This finding contradicts the statement of Figure 16, where at 7% of the cases, spinal column injuries were the most severe injuries. It is questionable whether this is due to the fact that relatively more autopsies were performed on pedestrians and cyclists. The remaining body regions of the upper and lower extremities play an underpart where the location of severe injuries is concerned. Only with decreasing injury severity, the lower extremities seem to be more frequently represented.

Figure 16 gives an overview over the distribution of the most severely injured parts of the body for persons, who were fatally injured in Lower Saxony in the year 2003 in the course of a traffic accident. This information originates from the public

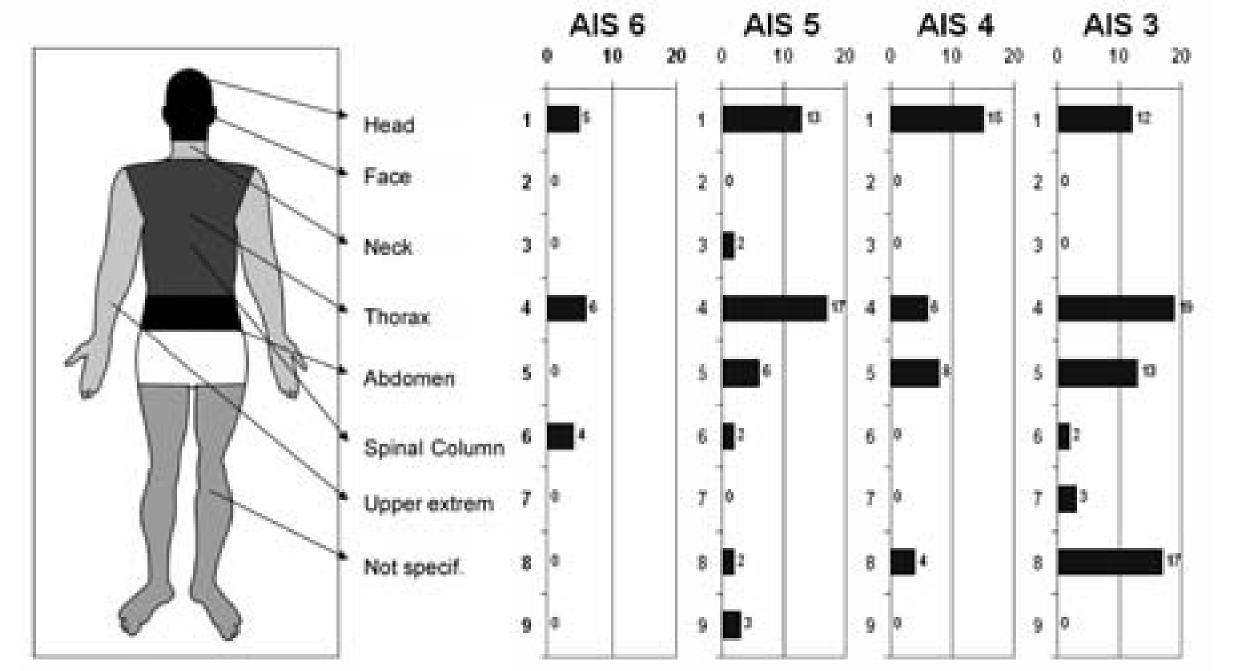


Figure 15: Distribution of the injuries of the 4 most serious degrees of injury severity (AIS 3 to AIS 6) on the corresponding body part

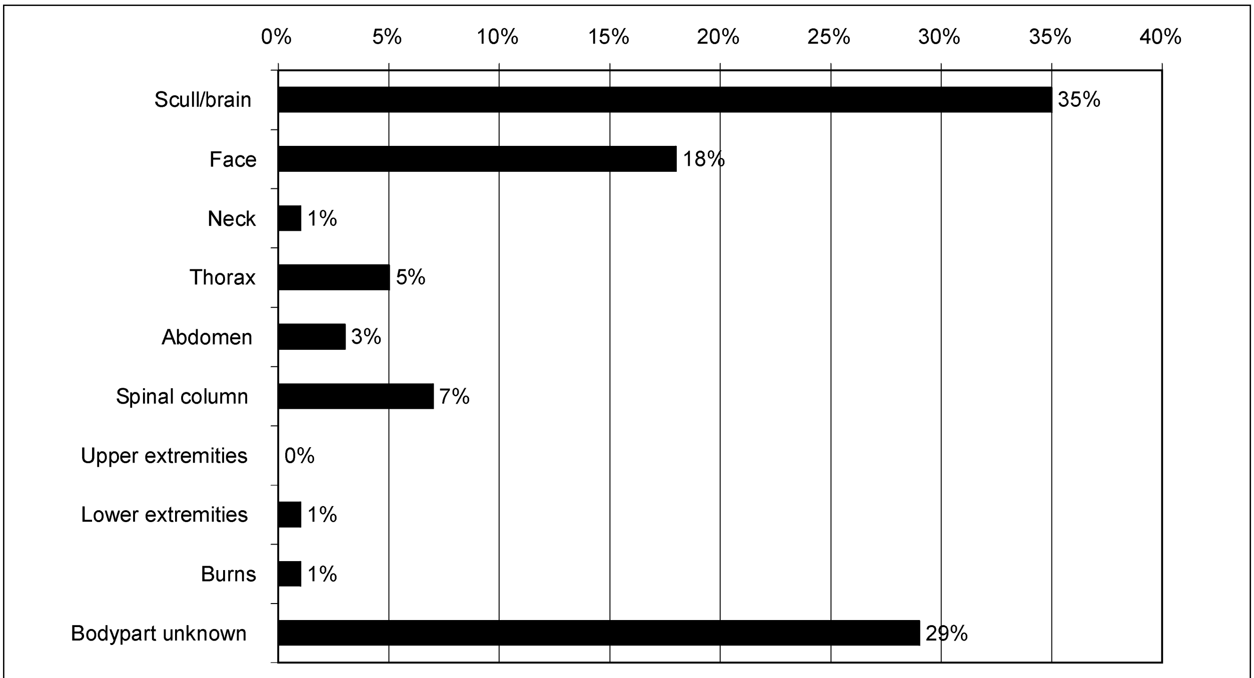


Figure 16: Distribution of the most severely injured body parts of persons fatally injured in traffic accidents in Lower Saxony in 2003

prosecutor's files of inquiry and the physician reports and autopsy reports contained in them. In 12% of all cases such documents were available, in 75% of the cases these could be gleaned from death certificates or police reports, however not in an exhaustive manner. Only for 146 fatalities of altogether 225 in the database containing 202 accidents, the most severely injured body parts could be determined.

It can be read from Figure 16 that injuries of the head are frequently the most severe injuries of traffic fatalities and thus represent the most frequent cause of death for the persons involved in fatal accidents. With the exception of injuries of the spinal column and the thorax the other parts of the body are rather underrepresented.

Conclusion and Discussion

Recapitulatory, it can be stated that the selected methodology of the analysis of traffic accidents based on information from the public prosecutor's files of inquiry offers quite a good base of scientific analysis and data acquisition after conclusion of the forensic procedure. The methodology "Statistical Analysis of Prosecution Accident Cases" is called SAPAC. Such a methodology offers an additional possibility at a justifiable expenditure of scientifically using the collected information of a forensic public prosecutor's preliminary investigation, beyond the possibilities of the statistical accident documentation by means of police reports and the detailed in-depth investigations with very comprehensive and detailed information, concerning vehicle deformation, local accident conditions and injury details, conducted by scientific teams. By the application of the legal framework conditions of data security for scientific use, the possibility of data acquisition and analysis for scientific purposes is given.

In the context of this study, a process of random sampling and a methodical procedure for the scientific use of the public prosecutor's files of inquiry were developed and a data base for the analysis of accidents was established, here using accidents from the German state of Lower Saxony, called FALS (Fatal Accident Data Lower Saxony), in order to determine the accident structure and injury situation of killed road users with SAPAC. In contrast to the analysis of the data of the official statistics, the public prosecutor's files usually contain more comprehensive information concerning the sequence of the accident, the causes as well as the damage and injury patterns.

The study showed that in fatal accidents frequently speed is a parameter substantially affecting the accident. Accidents on state and federal highways constitute the major share (approx. 60%), 80% occurred outside urban areas. Head and thorax injuries are among the most severe injuries.

Occupants of cars were frequently killed in curve accidents, pedestrians while crossing a road away from pedestrian crossings, bicyclists when turning and crossing privileged roads with traffic from the left. Motor cyclists were frequently killed when turning left and colliding with oncoming vehicles. Truck drivers frequently suffered fatal injuries in accidents in longitudinal traffic.

The study showed a good method for extracting information, which is otherwise not possible using the typical national statistics on the basis of the unchanged police reports. With this type of collection on the basis of the files of inquiry of the public prosecutor's offices and courts SAPAC, the average of 160 accident characteristics for each accident are usable. This is a fraction of the information gleaned from large-scale in-depth investigation teams. For example, in GIDAS for each accident about 2000 to 3000 items of information are collected. But the FALS database supplied a good overview of the accident structure and the corresponding injuries. A comprehensive study of the causes of accidents cannot be accomplished on the basis of this information. One is limited to the information given by the police, witnesses and the expert, all of whom are not present to an equal degree in all cases and therefore differ in quantity and quality. The data base permits statements concerning the avoidability of fatal accidents, however. In 8% of the cases, where passenger cars caused the fatal accidents, the accident would have been avoidable, 38,5% of the passenger car drivers that did not cause the accident, could have avoided it. This demonstrates the possibilities of the acquisition of detailed information by means of SAPAC, whose data structure is described in Table 1 in the Annex.

SAPAC can also be used to supply statements concerning the types of head injuries. Thus brain injuries and fractured skulls turned out to have occurred particularly frequently for killed passenger car occupants, which with a larger amount of cases could also be depicted for different collision speeds and EES values (Energy Equivalent Speed). The opportunity of making very detailed evaluations from the database requires breaking the total collective down to few cases for certain questions. Only 1 applicable case emerged, when head injuries of car occupants were known and EES in the case of passenger cars turning left was available. Thus in-depth analyses based on this methodology are limited. This deficit can be met only by increasing the number of cases. It would be sensible in this context to either extend the radius of action to several states or to analyze the data collected for several years, in order to be able to analyze positive and negative developments or trends.

That process of data collection and data analysis from public prosecutor's files of inquiry and court records SAPAC, selected here as a methodical approach, appears sensible and should be continued further. Here the data base FALS (Fatal Accidents Lower Saxony), established using accidents from the year 2003, is available and is scientifically usable.

References

1 H. APPEL, U. WANDERER, J. BLÖDORN: Forschungsbericht Nr. 206, Technische Universität Berlin, im Auftrag der Bundesanstalt für Straßenwesen, 1976

2 E. SCHULLER, G. BEIER: Verletzungsmechanische Fragestellungen bei der Rekonstruktion von Verkehrsunfällen, Kongressbericht der Deutschen Gesellschaft für Verkehrsmedizin e. V. im Auftrag der Bundesanstalt für Straßenwesen, Heft 56, 1986

Annex

General accident data	Traffic lights present	Trailer used	Personal/inury data
Day of week	Road surface type	Alcohol involvement	Seat row
Autopsy report available	Condition of roadway	Blood alcohol level	Seating position
Technical expertise available	Surface contaminants	Drug involvement	Driver y/n
Local area	Construction site present	Drivers licence since	Seatbelt used
Accident category according to the NLS	Bicycle lane/type	Driver is foreigner living in	Ejection from vehicle
Accident type according to the NLS	Lighting conditions	Nationality of driver	Entrapment
Accident category acc. to CARE defin.	Weather conditions	Nationality of veh. license	Person run over
Accident type according to the ISK	Fog present	Is driver owner of vehicle	Age
Accident kind according to the NLS	Visibility	ABS	Sex
Amount of involved cars	Strong winds	ESP	Hight of person
Amount of involved trucks	Transient factors	Vehicle manufact/type code	Weight of person
Amount of involved two-wheelers	Artificial lighting	Vehicle type	Marital status
Amount of involved pedestrians	Traffic calming	Car body style	Occupation
Amount of vehicles damaged	Division of lanes	Amount of doors	Suicide
Amount of involved poeple not injured	Type of crossing	Drive of vehicle	Injury severity
Amount of involved poeple slightly injured	Alignment of roadway	Color of vehicle	Consciousness arrival first aider
Amount of involved poeple heavily injured	Vehicle specific data	Engine power	Taken to hospital
Amount of involved poeple killed	Type of accident participant	ccm	No. of night in hospital
Total damage in EUR	Manufacturer	Vehicle max. speed	Died at scene
Accident with influence of alcohol	Vehicle model	Amount of axles	Days to death
Object struck off road	Amount of occupants	Driven axles	Bodyregion of heaviest injuries
At least one tow-away vehicle	Accident causer according to police	Kerb weight	Injury description
Hit and run	Vehicle movement before accident	Max. permitted weight	AIS-code
Accident with animal involvement	Accident evasion manoeuvre	Year of manufacure	Road user type specific var.
District	Omitted reaction of driver	Age of vehicle	Airbag availability
County	Driving direction before accident	Has veh. passed mand. inspection	Airbag deployment
Community	Collision type	Hazardous cargo	Helmet used
Collision type	Collision angle	Hazardous cargo classification	Reflecting clothing used
Roadway specific data	Amount of collisions	Hazardous cargo discharged	Bicycle lane available
Road classification	Driver/Pedestrian handicapped	Most heaviliy injured occupant	Bicycle lane used
Local area	Hit and run	Place of damage	Direction of collision
Type of road	Accident cause 1 according to NLS	Interacted with	Type of Motorcycle
Driving-direction of accident causer	Accident cause 2 according to NLS	Vehicle catch fire	Helmet type
Type of vincinity	Accident cause 3 according to NLS	Vehicle submersion	Dedicated Motorcycle clothing
Traffic density	Accident avoidable acc. to expertise	Vehicle tow-away vehicle	Helmet lost on accident
Roadway characteristics acc. to NLS	Collision speed according to expertise	3rd column of CDC	Chin strap torn apart
Particularities according to NLS	Speed before accident	Jacknife	
Amount of lanes in incr. direction	EES according to expertise	Vehicle roll over	
Amount of lanes in decr. direction	Object hit off road	Vehicle came to rest on	
Amount of lanes in both directions	Is vehicle defect a cause	Vehicle width	
Speed limit	Reckless driving before accident	Vehicle lenght	
Type of speed limit	Type of vehicle according to NLS	Damage on vehicle in EUR	

Table 1: Variables of FALS Data base

Y.W.R. de Vries
TNO-Automotive Safety, Delft, The Netherlands

N.A. Jongerius
DAF Trucks, Eindhofen, The Netherlands

Method For In-Depth Traffic Accident Case-Control Studies

Abstract

Internationally, the need is expressed for harmonized traffic accident data collection (PSN, PENDANT, etc.). Together with this effort of harmonization, traffic accident investigation moves more and more in the direction of accident causation. As current methods only partly address these needs, a new method was set up. The main characteristics of this method are:

- Accident/injury causation (associated) factors can objectively be identified and quantified, by comparison with exposure information from a normal population.
- All relevant accident and exposure data can be included: human-, vehicle-, and environmental related data for the pre-crash, crash and post-crash situation (the so-called Haddon matrix). The level of detail can be chosen depending on interest and/or budget, which makes the method very flexible.

In this paper the accident collection and control group method are presented, including some of the achieved results from a pilot study on 30 truck accidents and 30 control locations. The data were analyzed by using cross-tabulations and classification-tree analysis. The method proved useful for the identification of statistically significant causational aspects.

Notation

N Number of virtual accidents

n_m Number of vehicles in main direction

n_o Number of vehicles in other directions

γ Environmental impact

M Maximum number of virtual impacts (set at 10.000)

A_m Allowed number of vehicles in the main direction

A_o Allowed number of vehicles in the other directions

N_i^A Number of vehicles of type *i* in the maximum allowed sample

N_i^V Number of vehicles of type *i* in the video sample of duration *D*

D Video duration in minutes

W_i Weight factor for vehicles of type *i*

W_{ij}^I Weight factor for the impact between vehicles of type *i* and *j*

L_k Available percentage of road type *i*

N_k^s Number of locations sampled for road type *i*

W_k^L Weight factor for the location *i*

Introduction

Traffic accident investigation is used more and more to address all cells of the Haddon-matrix (see Figure 1). The information from this matrix is used to deploy new activities in relevant areas.

Knowledge on primary safety and pre-crash aspects (i.e. avoiding accidents) requires information about accident causation. Data bases and methods that have been developed for accident causation studies (e.g. EACS, ETAC) up till now, belong to the case-series studies: cases are investigated and frequency counts give information on occurrence of possible risk factors in these accidents. The impossibility to relate these occurrences to reference data is a large drawback as will be shown later.

A new method has been set up, with the main aim to address the afore mentioned limitation. The main objectives of this paper are to discuss the principles of this newly developed method for an epidemiological study into accident causation, and to show the results of a first pilot analysis on truck accidents.

The work has been carried out by TNO, with the support from DAF Trucks, Scania Trucks, and the Dutch Ministry of Transport, Public Works and Water Management and the Dutch Ministry of Economic Affairs.

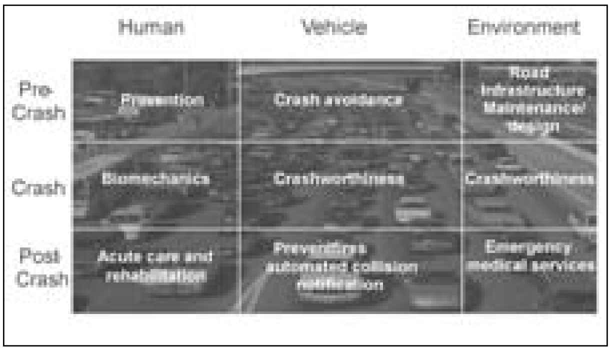


Figure 1: Example of the Haddon matrix

Exposure

Correct information about the cause(s) of accidents is relevant for policy makers and vehicle manufacturers. Identification of accident causes requires the acquisition of large amounts of data per accident, and a correct interpretation of this data (accident reconstruction, etc.).

Incorrect knowledge on accident causes may lead to the implementation of non-effective countermeasures. Such incorrect knowledge may be due to exposure effects or subjective assessment by investigators. High frequencies do not necessarily indicate a risk, but also show the amount of exposure. The investigator's subjectivity can originate from pre-determined ideas and feelings about what the normal operation should be under certain circumstances. These ideas are not necessarily correct and may lead to misjudgments. Therefore some kind of reference data is needed to correctly identify risk factors. A literature survey was carried out to find previously used study setups which made use of reference data. Possibilities for obtaining such observational data are the following:

Internal control groups
Internal control groups are groups of accidents for which a specific parameter is assumed not to have any influence. Differences in the presence or absence of the parameter in the studied group and the control group can indicate a relationship with accident occurrence. Two main problems exist: many cases have to be present and it has to be sure that the parameter under study has no effect in the control group.

Global indicators
Sometimes global indicators (kilometers driven, etc.) are used as reference data to indicate potential problems. However, the results are very dependent on the indicator that is used [ELSEVIER, 1997] and can be tuned with the use of an indicator which provides the results that are wanted. Furthermore, global indicators can not go into the detail needed for accident causation research (e.g. type of use).

Cohort study
Because traffic accidents have a relatively low occurrence, cohort studies are inefficient. Z group of drivers should be followed for a certain period. During this period some accidents should occur in this group. Drivers with and without accidents can be compared. The presence of accidents in this group is expected to be quite low when the group is not very large or the study duration is not very long.

Case-control study
When a case-series study is extended with the collection of some sort of control group, which can be used as reference data a case-control study design is obtained, from which associations between factors can be obtained.

Because in-depth research is already a case-series study, extension to a case-control study is therefore the most logical approach. A recent example is the European Motorcycle Accident In-Depth Study (MAIDS) [OECD, 1999], carried out in five countries, in which drivers were interviewed at gas stations. Another option sometimes used is to question drivers passing through the same scene one week after the accident. In both cases analysis on environmental factors was not possible because of the chosen method. Driver cooperation was also a problematic issue. However, both methods served as a basis for the newly developed method presented in this paper.

Method

Virtual accidents

In order to compare accidents directly with exposure information in a case-control study, the data need to be in the same format. Therefore one would like to obtain the control group from normal traffic situations, which can directly be compared with the accidents: some kind of "virtual accident" (every accident that could have occurred). Traffic intensity can be used as a measure. The number of "virtual accidents" for a given location can then be calculated by:

$$N = n_m \left((n_m - 1) + n_o + \gamma \right) \quad [1]$$

Each target vehicle (in this study a truck) has a virtual accident with every other vehicle passing through the scene. The number of virtual impacts is therewith frequency induced. The more other vehicles are present, the more virtual impacts. Each vehicle can have an impact with a vehicle in the same direction as well as with a vehicle from another direction or with an environmental object (see formula [1]). Environmental information of the location has to be coded with the virtual accident. The total of all virtual impacts in all monitored traffic situations will then serve as the control group.

A main problem with the virtual impact method is that the number of impacts increases quadratically with each extra vehicle in the main stream. Therefore the number of generated virtual impacts is limited to ten thousand per location. The maximum allowed number of vehicles for this maximum number of virtual impacts that has to be sampled for the main stream (A_m) and the other directions (A_o) is calculated according to formula [2].

$$f = \frac{n_m}{n_o} = \frac{A_m}{A_o}$$
$$M = A_m \cdot \left(\left(A_m - 1 \right) + A_o + \gamma \right) \Rightarrow$$
$$A_m = \sqrt{\tfrac{f}{f+1} M} \qquad [2]$$

This maximum allowed number of vehicles is sampled randomly from the video sample to acquire the distribution of vehicle types on a specific location.

Interaction model

In practice the traffic system is rather complex. Driver, vehicle and environment interact in unknown ways (see Figure 2a). All information needed for the control group should therefore be investigated at the same time.

The “virtual accidents” have to be collected in the same area in which the accidents are collected and should represent the normal traffic situations in that area. Therefore, the inspection of the locations should be completely randomized over the research area, such that it represents the conditions in the accident collection area. The samples should be taken equally over the duration of the study and at random times. The method for sampling the locations is shown later.

The traffic counts can be obtained from video, together with driven speeds, manoeuvers, distances to other road users, color, etc. Extra information can be obtained by license plate detection, coupled with vehicle registration information. From all the vehicles passing through the location the drivers should be observed and interviewed, and the vehicles should be inspected similar to the accidents investigations. This imposes a practical problem, because not all drivers can be stopped and interviewed in a monitored scene. Even if a sample could be taken, this means that needs to be on an involuntary bases, otherwise biases are introduced. In many occasions this is not possible. However, there is a way around this when some conditions and assumptions are met.

Model assumptions

Two possibilities now arise. For (semi) permanent physical conditions for which we expect that they have no relation with the environmental conditions (e.g. gender, illness, etc.) a control group could be gathered at any given location, because the conditions will be randomly distributed over the environment (not necessarily over the vehicles). Transient conditions which may have an interaction with or are induced by the environment are more complicated (attention diversion, using cruise control on motorways). Non-environment related issues can be investigated by interviewing people about the frequency of use or habits. Environmentally related habits can also be investigated on a more global level by asking about frequency of use under specific circumstances. This method suffers (less) from the same problems as global indicators (see Exposure).

The other option could be to form a cohort of random drivers whose behavior is recorded/logged under occurring circumstances. This option is more complicated and time consuming, but the result is likely better. For financial reasons the interviewing method is chosen for this study.

The driver information will be obtained at convenient locations which are sufficiently randomized. Drivers are interviewed and vehicles inspected.

The idea that is now used is the following (see Figure 2b): The driver interviews and detailed vehicle inspections are treated as missing values in the data from the video observations. These missing data are imputed from the separate vehicle inspections and interviews on the video information. The random imputation is conditioned (matched) on variables collected in both inspections (so-called conditional random imputation). These values may not be treated as real values per accident but can be used to make appropriate inferences and to show statistical associations. The vehicle type distribution does not have to match the one found from the video observations and can deliberately be biased towards groups of interest to obtain the most useful information. The parameter for which the bias is introduced should also be measured from the video data (vehicle type, color, etc.). It would not lead to a biased sample, because the distribution of generated virtual accidents would stay the same, only with more or less details and statistical certainty for specific groups.

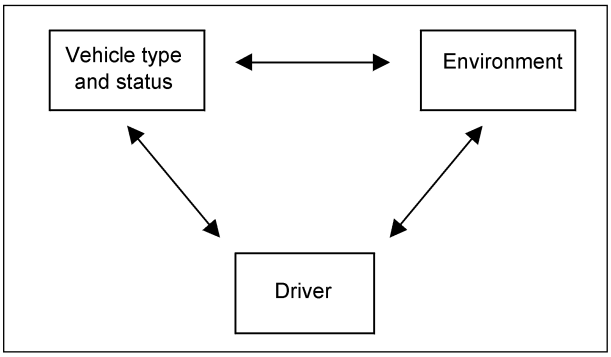


Figure 2a: Main interactions

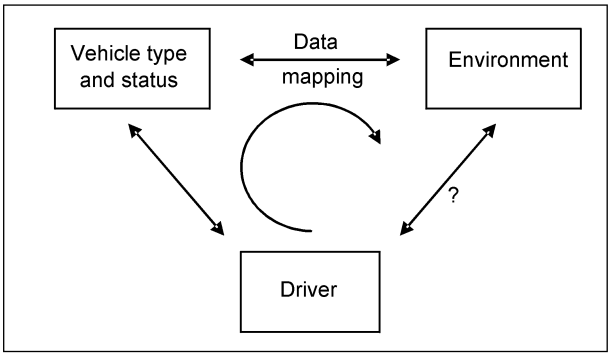


Figure 2b: Model assumptions and imputation

In future projects multiple imputation techniques can be used in order to improve the prediction of the missing values [RUBIN, 1987]. For this pilot study this method has not been used yet.

Practical Implementation

Selection of randomized locations

Information on all Dutch roads is available from a Geographic Information System (GIS) database (see Figure 3). Most other countries also have mapped their (main) roads into vector based files that are compatible with GIS [GIS, 2004]. The location selection has been split into crossings and segments without crossings. In order to sample all roads equally, all segments have been divided into 25 meter sections. Sampling the number of lanes instead of the number of roads is more appropriate, so that the traffic flow on one-way streets and multiple-lane streets are sampled just as much as on two-way streets.

For crossings the following approach is taken: Each lane into the crossing is counted as an intersection, because vehicles may come from all directions. Roundabouts are considered to be sets of T-crossings with two in-coming lanes and one out-going lane. This is the same as considering it to be one crossing, due to the fact that the number of manoeuvers is limited in the multiple T-crossing approach.

Figure 3: Example of a GIS-location and the low visibility video pole clamped to a lamp-post

A (disproportionate) stratified sampling plan may be used if specific road types are of more interest to the researcher. For this study stratification was used. The road types that were expected to have a higher accident occurrence, were sampled with higher frequency to obtain more detail for those roads.

Obtaining the control group information

In Figure 4 the workflow is depicted. Traffic lanes are randomly selected in the accident collection region and will serve as the main traffic streams. All lanes and the scenes are recorded on video for approximately 30 minutes from a high location (a low visibility extendable beam; see Figure 3) to reduce parallax effects in the analysis of speeds and distances. With special developed software and markings on the road with known distance to each other, the speed and distance to other vehicles can be obtained from the video. For trucks extra information is recorded that will improve the conditioning (matching) for the required conditional random imputation.

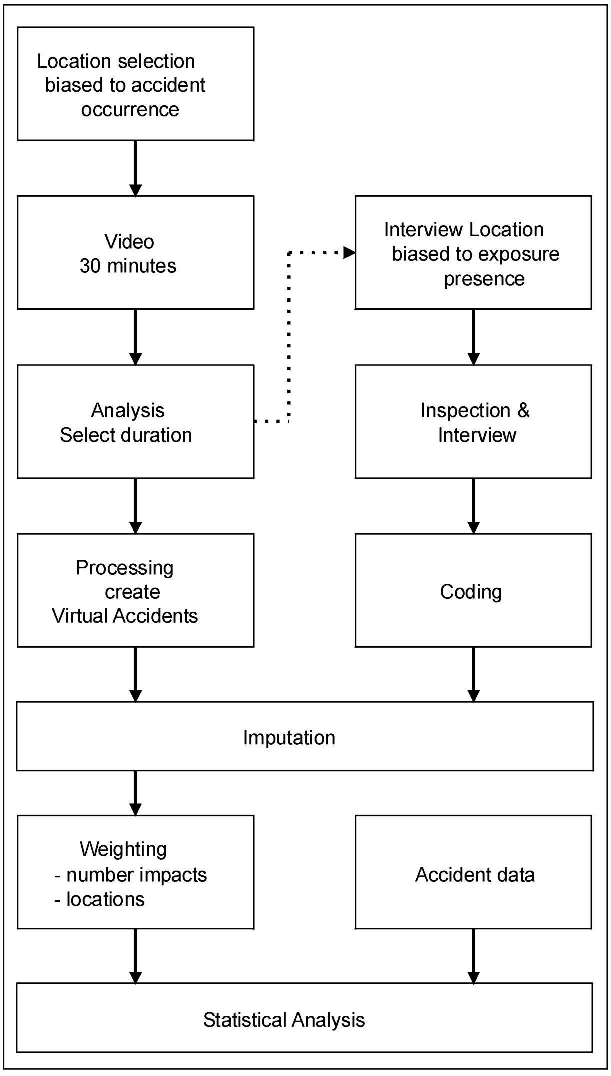


Figure 4: Work flow diagram

The interviews were done at restaurants, gas stations, distribution centers and companies using (specific) trucks. The selection of truck types was matched to the distribution observed in the accident sample, again to obtain a maximum of detail with minimum effort. In doing so, a bias was introduced in the interviews. This only results in a larger sample with a higher confidence level for the vehicles of interest, and less certain information for the other vehicles. A comparison will have to be made between accident trucks of the same type (e.g. on mirror adjustments) in the analysis, for which a sample with higher confidence level is beneficial. Not all truck types could be investigated with the limited sample.

Data weighting

A problem which manifested itself is that due to several reasons the video duration of 30 minutes was in more than one occasion not 30 minutes. Another aspect is that analyzing 30 minutes of motorway video is time consuming and not really necessary to obtain a stable distribution. Thirdly, the number of virtual impacts that are created is limited. Therefore a sample of the video is taken. This made it necessary to assign a weight factor to each vehicle according to the following formula:

$$W_i = \frac{N_i^V}{N_i^A} \cdot \frac{30}{D} \qquad [3]$$

The sum of vehicles of type i in the maximum allowed sample (N_i^A) equals the sum of the allowed number of vehicles from formula [2]:

$$\sum_i N_i^A = A_m + A_o \qquad [4]$$

The weight factor for each virtual impact dependents on the involved vehicles and was established in the following way:

$$W_{ij}^{\ I} = W_i \cdot W_j \qquad [5]$$

After establishing these weight factors per vehicle and virtual impact on a given location, the locations had to be weighted towards their real presence in the sampling region:

$$W_k^{\ L} = \frac{L_k}{N_k^{\ s}}$$
$$W_{ijk}^{\ LI} = \left(W_{ij}^{\ I}\right)_k \cdot W_k^{\ L}$$
$$W_{ik}^{\ LV} = \left(W_i^{\ V}\right)_k \cdot W_k^{\ L} \qquad [6]$$

These weight factors were used throughout the analysis.

Results

The authors want to stress that the results presented in the following sections can only serve as an indication and merely show the analysis possibilities because the sample of accidents is limited.

Accidents and control group population

For this study 30 truck accidents were investigated. The Dutch Accident Research Team (DART) was notified by the technical police departments in the province of Zuid-Holland. The technical police departments in these regions are notified of all truck accidents and measure accident (skid) marks in detail. All accidents for which TNO was notified were investigated by the investigation team. The total sample is biased towards more severe accidents. Comparison with the control group therefore gives information about severe accidents.

Of these accidents, 15 occurred on straight segments and 15 on crossings. The road types (urban, motorway, etc.) of the control group population were matched with the accident occurrence road types and weighted afterwards to obtain a maximum of accuracy and detail.

Example analysis

In Table 1 the frequencies of collision partners in the accident cases and in the virtual accidents (control) on intersections are shown. The adjusted residuals indicate whether the cases and controls differ significantly and may be interpreted as follows: an absolute value larger than two indicates for normal distributions a 95% certainty that a significant difference is present [SPSS, 1998]. The sample in this pilot-study is unfortunately too small to satisfy the condition of normality, therefore only indications can be given. From the presented table it can be read that motorized two-wheelers and bicycles are more present in the accident cases than in the control group. If the sample were large enough, this would indicate that the probability to be in an accident as a bicyclist or motorized two-wheeler is higher than for example a car driver.

A classification tree analysis [SPSS, 1998] with a forced split on vulnerable road users (motorized two-wheelers, bicycles and pedestrians) was used to identify aspects in truck-vulnerable road user impacts, which were found to have a high probability of occurrence (see Appendix). The variables in the classification tree were the manoeuvers of the truck and vulnerable road user with respect to each other.

Compared with the virtual truck accidents (frequency of occurrence of normal meetings) with vulnerable road users (VRU) two groups can be identified with differences in occurrence:

- Truck turning right, with the original driving direction identical to the VRU driving direction. This situation was never observed in the virtual accidents. Not shown is that this occurs in all investigated cases on local small roads and that the VRU is going straight or is turning right. This

			Case		
			Case	Control	Total
OV1: Object type	Truck	Count	0	14158	14158
		% within Case	.0%	6.6%	6.6%
		Adjusted Residual	-1.0	1.0	
	Car	Count	3	170786	170789
		% within Case	20.0%	79.6%	79.6%
		Adjusted Residual	-5.7	5.7	
	Motorised 2-wheeler	Count	3	354	357
		% within Case	20.0%	.2%	.2%
		Adjusted Residual	18.8	-18.8	
	Bicycle	Count	6	1008	1014
		% within Case	40.0%	.5%	.5%
		Adjusted Residual	22.3	-22.3	
	Bus	Count	1	3145	3146
		% within Case	6.7%	1.5%	1.5%
		Adjusted Residual	1.7	-1.7	
	Van	Count	1	24900	24901
		% within Case	6.7%	11.6%	11.6%
		Adjusted Residual	-.6	.6	
	Other vehicle	Count	0	8	8
		% within Case	.0%	.0%	.0%
		Adjusted Residual	.0	.0	
	Pedestrian	Count	0	12	12
		% within Case	.0%	.0%	.0%
		Adjusted Residual	.0	.0	
	Stationary object	Count	1	166	167
		% within Case	6.7%	.1%	.1%
		Adjusted Residual	9.2	-9.2	
Total		Count	15	214537	214552
		% within Case	100.0%	100.0%	100.0%
a. Junction = Yes					

Table 1: Comparison between collision partners in accident cases and in virtual accidents on intersections (The distributions differ significantly. Chi^2-test: $p<0.05$). Cases represent accidents and controls represent virtual accidents

is typically the situation in which blind angle aspects are considered relevant.

- Truck is going in the opposite direction from where it comes from (driving backwards); while in the control group this situation is never observed. This is possibly also a blind angle aspect, but on the rear of the truck.

Discussion

On the method

An aspect that is more difficult to investigate with this study setup is the environmentally related driver behavior: whether an association exists between certain driver behavior and the environment (e.g. cruise control on motorways, use of mirrors at certain locations). When it is expected that these factors play an important role, the relationship can be investigated by implementing questions regarding these relationships in the interviews. Frequency of use under various conditions can be asked. Another more expensive method already mentioned is to form a cohort of random drivers for which the behavior and actions are recorded in some way, possibly by actually monitoring the driver and recording and coding the behavior. Again it is not required that the population matches the exposure information from video.

Night time control samples caused some problems. Video information with “night shot”-mode was not of very good quality.

On the results

From the classification tree in the Appendix it can be seen that right turning trucks and VRU’s coming from the same direction have a relatively high number of cases (3) with respect to the control group (0). At the top of the classification tree this was (10 cases/ 250 controls). However, many more virtual bicycle accidents would have been present if due to chance a location near a school was sampled in the small control group or sampled at hours at which children and students bike to school. Therefore no real conclusions may be drawn from this sample. When the sample would have been large enough and the same situation would persist it might have been concluded for these cases that situations with right turning trucks and VRU’s coming from the same direction impose a greater accident probability than other cases. It then could be suggested that this relates to blind angle aspects.

With more cases the classification tree analysis could go further. If any control group cases would be present for these typically dangerous situations a comparison between environmental, driver or truck-related issues could be made to show typical problems for these locations. But at this time, no control data is available and the number of accidents is clearly limited.

Although potentially influenced by the coincidental choice of control locations, the method of analysis seems to indicate a potential risk factor that was also identified in national statistics [de VRIES, 2000]. The conclusions from the national statistics were based on assumptions about exposure. This in-depth analysis shows that this can be supported objectively with control-group information. Details concerning mirror adjustment, road layout can give more details about exact causation-related aspects. Again comparison with control group information can show discrepancies between the two data sets. This information can be further supported by objective and subjective descriptive information.

Risk adaptation and secondary safety

This method could also identify certain driver behavior and driver risk assessment. The exposure data and injury probability data can be used to calculate driver risk, the risk a driver “feels”:

Relative risk (*K* in accident type)=
P (*K*| accident type) χ *P* (accient type) [7]

The relative risk for being killed (*K*) in a certain accident type equals the probability to get killed in a certain accident type times the probability that such an accident occurs. The relative probability for occurrence can be obtained from the exposure data. If this occurrence probability is very low, but the consequences still high, a driver might still feel quite safe. When the occurrence probability is high and the probability is also high this will be perceived as dangerous.

A certain safety feature could induce more-unsafe driving (risk adaptation). Exposure data can show that this may be the case if discrepancies exist between the accidents population and the exposure population in the presence of secondary safety features. Suppose the degree of implementation in the normal population of a secondary safety feature is found to be 50% (e.g. frontal airbag), one would expect to find a same or less relative accident probability (number of accidents divided by the number of virtual accidents in that category) for cars equipped and cars not equipped with airbag. Airbags are supposed to reduce injuries, so some accidents will not be reported to the police anymore or will not be included in the study sample, therefore a lower accident probability is expected. If one would find a higher accident probability for cars equipped with airbags, but still a lower probability to get injured one may conclude that risk adaptation has occurred, reducing the expected benefit. Measuring the degree of implementation based on for example car sell rates or kilometers driven should be done only with extreme care (see Introduction).

Conclusions

From the literature study it was learned that a case-control study is best suited for in-depth traffic accident research at this time. No good documented case-control study could be found which includes environmental, driver and vehicle information. Therefore the new method was developed.

- A case-control group study with real and "virtual accidents" was developed and tested on 30 accident cases and 30 random locations.
- Data imputation could technically be realized. A validation was not yet possible because of the small sample.
- Injury causation analysis can be done in great detail. A large amount of data analysis possibilities exist. The analysis possibilities seem to give good information and indications to find problems in accident and injury causation from which new solutions may be derived.
- Risk adaptation for primary and secondary safety features can be assessed.
- Environmental, human and vehicle factors can be investigated together, taking into account the relationship between the factors.
- The results from this study, although limited, are in line with results from other studies.

Recommendations

When defining measures for improved safety, it is recommended to include a dedicated exposure evaluation in order to determine with statistical significance whether, and up to what extent, actual safety improvements can be expected. The case control method presented here is a good approach.

The exposure method should be evaluated on a wider scale, preferably European-wide to effectively indicate risk factors. European projects like SafetyNet or TRACE might provide a good basis.

References

S.L. BANGDIWALA (2000): Methodological Considerations in the Analysis of Injury Data: A challenge for the Injury Research Community, Injury Prevention and Control, Taulor & Francis, ISBN 0-748-40959-9.

DOT (2005): http://www.minvenw.nl/dgg/dodehoek/Zichtveldprobleem/Feitenencijfers/#feiten

ELSEVIER (1997): De kans op een ongeluk, 6-9-1997

GIS (2004): http://www.gis.com/whatisgis/index.html

OECD (2001): Motorcycles: Common international methodology for in-depth accident investigations

D.B. RUBIN (1987): Multiple imputation for non-response in surveys, John Wiley & Sons, New York.

SPSS (1998): AnswerTree 2.0 user's Guide, ISBN 1-56827-254-5

Y.W.R de VRIES (2000): Accident analysis of heavy trucks, TNO Report, 00.OR.BV.053.1/YdV

Y.W.R de VRIES (2005): A method for control group data to find accident and injury causation factors in in-depth traffic accident studies, TNO Report, 05.OR.SA.034.1/YdV

Appendix

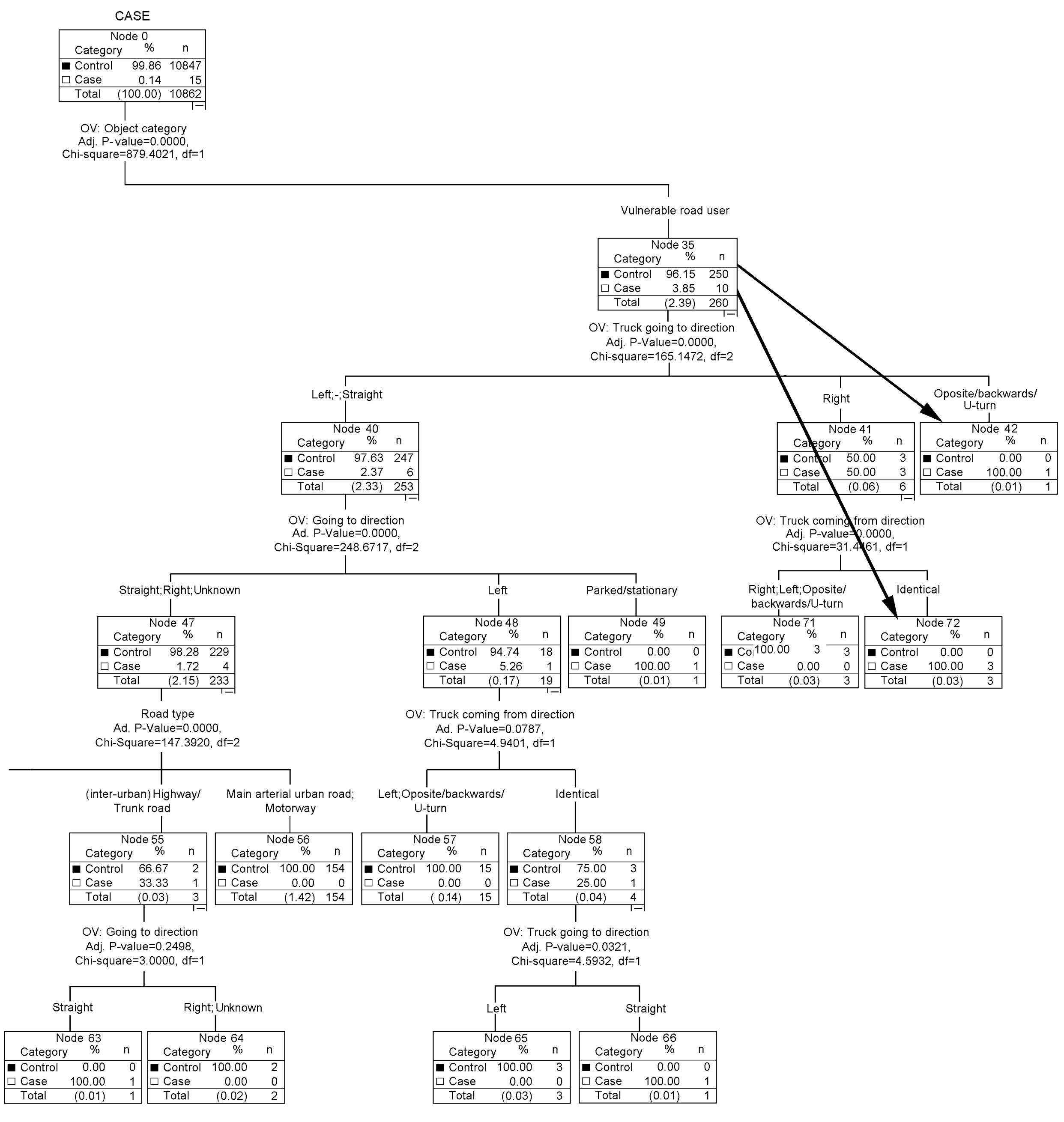


Figure 5: Classification tree. Explanation of the used terminology: underneath vulnerable road users: from the Other Vehicle (OV) perspective, the truck is going into a certain direction relative to the OV. Suppose the truck is turning right, then read: from the OV perspective the truck is coming from, e.g., the identical direction as the OV

Session:
Special Topics for Vulnerable Road Users

J. König, F.A. Berg

S.N. Huang, J.K. Yang, F. Eklund

C. Haasper, D. Otte, L. Knobloch, C. Probst, C. Krettek, M. Richter

J. König, F.A. Berg
DEKRA Automobil GmbH, Accident Research and Crash Test Center, Stuttgart, Germany

Powered Two-Wheeler Accidents – First Results of APROSYS SP 4 Implying GIDAS 2002 Data

Abstract

In recent years special attention has been paid to reducing the number of fatalities resulting from road traffic accidents. The ambitious target to cut in half the number of road users who are killed each year by 2010 compared with the 2001 figures, as set out in the European White Paper "European Transport Policy for 2010: Time to Decide" implies a general approach covering all kinds of road users. Much has been achieved, e.g. in relation to the safety of car passengers and pedestrians but PTW accidents still represent a significant proportion of fatal road accidents. More than 6,000 motorcyclists die annually on European roads which amounts to 16% of the EU-15 road fatalities. The European Commission therefore launched in 2004 a Sub-Project dealing with motorcycle accidents within an Integrated Project called APROSYS (Advanced PROtection SYStems) forming part of the 6th Framework Programme. In a first step, the combined national statistical data collections of Germany, Italy, the Netherlands and Spain were analysed. Amongst other things parameters like accident location, road conditions, road alignment and injury severity have been explored. The main focus of the analysis was on serious and fatal motorcycle accidents and the results showed similar trends in all four countries. From these results 7 accident scenarios were selected for further investigation via such in-depth databases as the DEKRA database, the GIDAS 2002 database, the COST 327 database and the Dutch element of the MAIDS database. Three tasks, namely the study of PTW collisions with passenger cars, PTW accidents involving road infrastructure features, and motorcyclist protective devices have been assessed and these will concentrate inter alia on accident causes, rider kinematics and injury patterns. A detailed literature review together with the findings of the in-depths database analysis is presented in the paper. Conclusions are drawn and the further stages of the project are highlighted.

Notation

IP	Integrated Project
SP	Sub-Project
PTW	Powered Two-Wheeler
WP	Work-package
AIS	Abbreviated Injury Scale

Introduction

More than 6,000 of the 40,000 fatalities on European roads in 2001 were related to powered two-wheelers (PTWs). Compared to the overall number of victims on the roads, this figure represents 15% of the toll of this dreadful aspect of our society. The European Commission has launched the 3rd European Road Safety Action Plan with the ambitious goal of reducing the fatalities by 50% by 2010. By 2025, it is intended that the number of persons killed or severely injured on the road each year shall be reduced by 75% compared with 2001. Against this background the EC launched the Integrated Project APROSYS (Advanced PROtection SYStems) within its 6th Framework Programme The APROSYS Integrated Project on Advanced Protective Systems is focussed on scientific and technology development in the field of passive safety. It concerns, in particular, human biomechanics, vehicle and infrastructure crashworthiness and occupant and road user protection systems. World-wide, vehicle safety experts agree that significant further reductions in fatalities and injuries can be achieved by using passive safety strategies. APROSYS aims to offer a significant contribution to the reduction of road victims in Europe. In other words, the general objective of the IP is the development and introduction of critical technologies that improve passive safety for all European road users in all relevant accident types and over all ranges of accident severity. Measures and strategies for powered two-wheelers are included within Sub-Project 4 dealing with motorcycle accidents. The purpose of this SP is to reduce the number and severity of user injuries associated with PTWs (including mofa/moped) for the most relevant accident types. This will be achieved by means of in-depth analysis of the different accident scenarios in which motorcyclists were involved (WP1). Interest is to be concentrated on "forgiving" types of road infrastructure features and design (WP2) and advanced protection systems for motorcyclists (WP3). As a first step within the context of WP1, data from various national statistical offices have been analysed. This included SP consortium data from Italy, Germany, Spain and the Netherlands.

National Statistics Analysis

Except for Italy the data from four different countries have been analysed for the years 2000 to 2002 [1]. In the case of Italy the years 1999 to 2001 were chosen because no data were available for 2002. For each country, the differences in data acquisition methods and database restrictions are described prior to the analysis. Therefore a comprehensive understanding of the results as well as of the limiting factors has been gained. A separation of the PTWs into mofa/moped and motorcycles has been made in order to highlight possible differences for the selected variables. A general summary of the PTW situation for the country concerned is followed by an analysis of the population characteristics such as gender and age patterns. The accident circumstances were split into area, time, month, road alignment, road conditions, weather and light conditions. Urban and non-urban areas have been separated. A more precise differentiation of the non-urban roads into highway and other roads has been made. As for the selection of the accident scenarios, which are further addressed in the following work-packages, the focus was on four main variables such as type of vehicle (mofa/moped or motorcycle), type of accident (single vehicle accident or various vehicles involved), type of road alignment (straight, bend, curve, etc.) and area (urban, non-urban). These variables have been cross-linked in order to obtain the different accident scenarios. The figures taken into account for the scenario definition focused only on severe and fatal accidents.

Italy

The analysis was carried out using the Italian accident database owned by the Italian Institute of Statistics (ISTAD) in which only accidents involving at least one injured person are included. It is not possible to distinguish between slight and severe injuries. Moreover, conclusions regarding helmet use cannot be drawn.

In Italy an increasing trend in the number of licensed PTWs is observable. Whereas the moped population remained almost constant, the number of motorcycles rose significantly from 2,967,906 in the year 1999 to 3,729,890 in the year 2001. The PTW group covers 21% of all licensed vehicles in the country. A powered two-wheeler was involved in 35% of all accidents in Italy while for 25% of all casualties at least one PTW was involved. In total, 235,409 accidents with personal injury were recorded in the year 2001, of which 82,451 were PTW accidents. As far as age groups are concerned, in urban and non-urban areas the group of drivers aged 26-35 years is the most significant one in terms of fatal motorcycle accidents and in urban areas the moped drivers aged 18-25 years are mostly involved in accidents resulting in injured persons. Regarding gender, the number of female PTW driver casualties is noteworthy, amounting to some 19%. It is worthy of mention that most fatal accidents involving both mofa/mopeds and motorcycles occur inside urban areas. This is also consistent with other recent studies, which reveal that Italy, Portugal and Greece are the only EC-countries where more fatal PTW accidents are recorded inside than outside urban areas [2]. In that context the vast mofa/moped population is a highly significant factor. The time of day when most accidents happen is between 6 p.m. and 8 p.m. and, as expected, the major proportion of those accidents happens in the summer period. As anticipated, the passenger car is the most frequent collision partner within PTW accidents in urban as well as in non-urban areas which occur on straight roads, intersections and bends. In terms of run-off-the-road accidents on straight roads and intersections, in most cases the kerb is hit, whereas on curves and bends ditches and safety barriers are the objects most frequently hit on rural roads.

Germany

The legal basis for compiling the data is the law and the Statistics of Road Traffic Accidents. Pursuant to this the Federal Statistics are compiled each year from accidents involving vehicular traffic on public roads or places, complete with the number of persons killed or injured and any material damage. According to the relevant law, the police authorities whose officers attended the accident are obliged to submit the report. This implies that the statistics cover only those accidents which were reported to the police. These are primarily accidents with serious consequences. To a relatively large extent, traffic accidents involving only material damage or slight personal injuries are not reported to the police. Since only aggregated data rather than raw data are available in the published yearbooks, some queries could only be pursued to a limited extent. Persons killed are defined as those persons who died within 30 days as a result of the accident, while seriously injured persons are defined as all those who were immediately taken to hospital for inpatient treatment (lasting over a period of at least 24 hours). The data review period covered the years 2000 to 2002.

Because the absolute numbers of killed and injured riders of PTWs since the early 1990s are more or less constant, the relative proportion they represent of the still decreasing number of all victims of road accidents in Germany shows a rising trend. Taking into account that e.g. the share of pedestrians killed in Germany over the years 1980 to 2003 decreased continuously, an increase in the proportion of the users of powered two-wheelers killed over the years 1992 (11.1%) to 2003 (16.6%) is noticeable, Figure 1. As far as the number of injured traffic participants in Germany is concerned, an upward trend in the share of the powered two-wheeler riders injured is also apparent.

In the year 2002 some 54 million licensed vehicles were on German roads and 9% of these were powered two-wheelers. The number of licensed PTWs has remained almost constant in recent years. In respect of all traffic accidents in Germany the involvement of PTWs plays a significant role. A powered two-wheeler is involved in more than 15% of all fatal and 18% of all severe accidents. In the years 2000–2002 most moped casualties were in the age group 18-25. Regarding motorcyclists alone, a shift from the age group 25-35 to the age group 35-45 is observable as far as number of casualties is concerned. This is true for both urban and non-urban traffic accidents where the PTW drivers involved are predominantly of male gender. Most PTW accidents occur inside urban areas. Within these road category statistics the most frequent injury level is the slight injury. As distinct from the motorcycle accidents where only 20% of the accidents with fatal injuries occur inside urban areas, the proportion of fatally injured mofa/moped riders inside urban areas is nearly 50%. Noteworthy is the fact that as far as motorcyclists are concerned the category of highway accidents associated with (mostly) elevated travel speeds is of minor significance in terms of the number of fatally injured PTW riders in general. Most of the

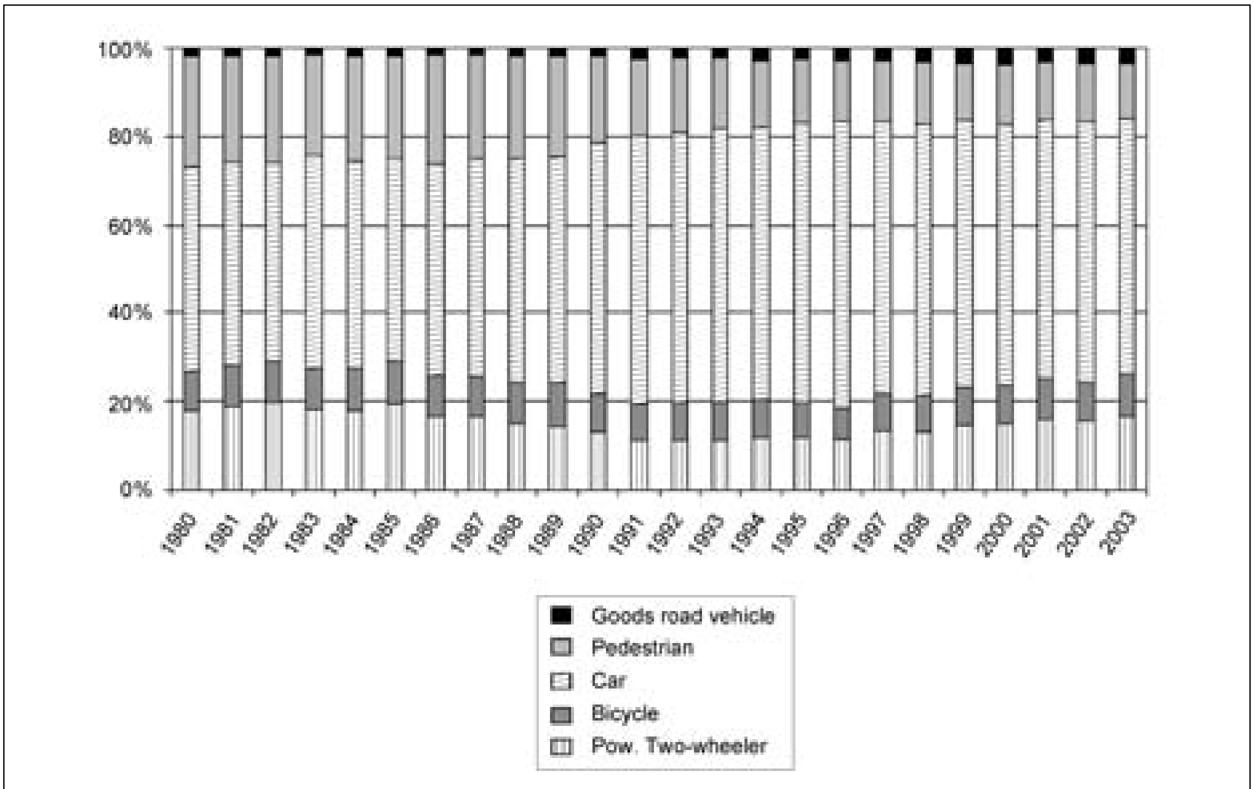


Figure 1: Time history of the specific shares of killed road users among each other in Germany for the period 1980 to 2003

PTW traffic accidents resulting in personal injuries take place in the period from spring to autumn. An observable small gap in July is related to the summer holidays in Germany. PTW accidents happen mostly in dry weather conditions, related to the fact that motorcycle riding is often a leisure activity. Wet and snowy/icy weather conditions are of interest regarding mofa/moped accidents. Here, mofa and mopeds are a common means of travel inside urban areas to go to work. Most PTW accidents take place in the daytime. A particular correlation between light conditions and injury severity is not detectable. In about 70% of the cases in urban areas and in about 45% of the cases in non-urban areas involving injuries to persons the passenger car is the other vehicle concerned. In rural areas the single vehicle accident is of special interest. In 46% of such accidents physical injury results. Because in Germany there are no public data available which deal with road alignment, individual PTW accident scenarios could singly be defined in a very restricted way.

The Netherlands

The VOR (Traffic Accident Registration) database is a national Dutch database of the Adviesdienst Verkeer en Vervoer (AVV). The AVV is part of the Dutch Ministry of Transport, Public Works and Water Management. The data in the database comes from police records. The nature of the report about an accident depends upon the severity of the accident: the more severe an accident is the better is the extent ad quality of the report. Regarding the injury level classification a fatality is coded when a person dies at the accident spot or if a person is hospitalised and dies within 30 days after the accident; a seriously injured person is coded if hospitalised.

The Dutch statistics for 2002 show a total of 8,676,393 licensed vehicles including 968,922 PTWs (11.2%). Mofa and Mopeds are roughly 4 times more common than motorcycles. In only 4% of all accidents a powered two-wheeler was involved but these were accountable for more than 17% of all fatalities and almost 26% of all seriously injured persons in the year 2002. During the last few years the overall trend in The Netherlands for PTW accidents has been downwards. The main age group of moped riders is the 16-18 year olds and for motorcycle riders the 25-35 year olds. This is true for both urban and non-urban areas and again the predominant gender of PTW users is male. Regarding accident location, most mofa/moped casualties happen inside urban areas on dry roads whereas no clear distinction is possible for motorcyclists. Although for motorcycles the proportion of urban and rural accidents is nearly the same, as would be expected the more serious accidents tend to happen outside urban areas. As far as the time of day of the accident is concerned, the rush hour in the evening between 3 p.m. and 8 p.m. is when most accidents occur. Even though road usage intensity statistics show a double peak with an additional one in the morning rush hour, inexplicably a concentration of PTW accidents at that time cannot be observed. Most of the accidents occur in the months where there are many PTWs on the road, in both early and late summer. During summer holidays in July the overall road use is less. The majority of PTW accidents occur on rural straight roads and at urban intersections with a car as the other vehicle involved, while motorcycles are associated with a significant share of severe single accidents taking place on curves outside urban areas. In more than 25% of all run-off the road accidents with PTWs involved a tree or a pole is hit.

Spain

The Spanish road accident database is managed by the DGT (General Directorate of Transport), a public organisation subordinate to the Ministry of Interior. The Spanish road accident database contains the whole population of accidents in Spain in which, at least, one person has been injured as consequence of the accident. Information contained in Spanish DGT database is collected by the police forces. In a reported accident between two vehicles the design of the database forms fails to distinguish which vehicle is the target and which one is the bullet. The variable “accident type” refers only to the global configuration of the accident, but there is no information regarding the kind of impact received by each vehicle. Regarding the injuries, the DGT database contains four categories of injured people: fatal, serious, slight and uninjured. Police agents judge the severity of the injuries and assign one of these values to each casualty. Furthermore, subsequent information about casualties is given within 24 hours and not within 30 days. To compensate for this deviation from the European standard, calculated correction factors are provided by the DGT.

In Spain 3,561,450 powered two-wheelers were registered in 2002. This amounts to 13% of all licensed vehicles in the country. A PTW was involved in more than 32% of all accidents with almost 22% of all accidents involving mofas/mopeds. In traffic accidents PTWs accounted for more than 14% of the fatally injured and nearly 23% of the severely injured persons in 2002, even though in recent years a decreasing trend for mofas/mopeds and an increasing trend for motorcycles is observable. Considering age groups, most of the fatalities and severely injured people are below 35 years old. In respect of mofa/moped users, casualties are younger than for motorcycle users as anyone can ride a mofa/moped once they are 14 years old. In Spain, too, the majority of PTW casualties is of male gender. Within urban areas the number of accidents is higher than outside urban areas. This is true for both categories of powered two-wheelers. These accidents usually occur on dry and clean roads in daylight in the summer period. As far as accident scenarios are concerned, large numbers of severe and fatal PTW accidents happen within urban areas at intersections and involve a car. Also run-off-the-road accidents with or without hitting a hazardous object are significant. Outside urban areas accidents at intersections, on straight roads or within a curve are highlighted.

Accident scenario selection

Following a study of the national statistics of the four different countries similar trends regarding powered two-wheeler accidents could be recognized. Although some minor differences (legislation issues, different vehicle classification etc.) have also been identified, their influence when selecting the main accident scenarios is of minor importance. When determining the most frequent and dangerous scenarios it is necessary to differentiate between those taking place in urban areas and those in non urban areas – see Table 1. Additionally, mofas/mopeds and motorcycles have been recorded separately. Consequently seven scenarios were identified as being the most significant.

Urban Area	Non Urban Area
Moped against car at intersections	Motorcycle against car at intersections
Moped against car on straight roads	Motorcycle against car on straight roads
Motorcycle against car at intersections	Motorcycle single vehicle accidents
Motorcycle against car on straight roads	

Table 1: Selected PTW accident scenarios

Taking the four analysed countries as a whole these accident scenarios can be listed in order of importance in terms of the total number of accidents which occurred:

- Urban – Moped – Car – Intersection.
- Urban – Moped – Car – Straight road.
- Urban – Motorcycle – Car – Intersection.
- Urban – Motorcycle – Car – Straight road.
- Non-urban – Motorcycle – Single vehicle accident.
- Non-urban – Motorcycle – Car – Straight road.
- Non-urban – Motorcycle – Car – Intersection.

The results derived from the national statistics analyses were intended to be further examined by means of in-depth database analyses. Rider and vehicle kinematics, accident causes and sustained injury patterns have been elaborated as well as detailed impact configurations.

In-Depth Database Analysis

Within the SP 4 consortium several in-depth databases were available to explore. From Germany the DEKRA database, the GIDAS 2002 database and the COST 327 database, from the Netherlands the Dutch part of the MAIDS database. The following database descriptions were extracted literally from the public project report and give a brief insight into the database origins, particularities and data restrictions [3]. As expected, not all the requested information was obtainable from the four databases so that the composite results are the best available in those circumstances.

DEKRA database

The fundamental basis of the DEKRA accident database is the accumulation of written expert opinions containing the accident analyses that are drawn up by skilled forensic experts at the DEKRA branches throughout Germany and totalling about 25,000 annually. The particular feature of these reports is that normally the experts are called by the police or prosecuting attorney to come to the accident scene directly after the accident happened. They have to answer case specific questions in their expert opinions. Therefore they have the right to determine the accident circumstances, which includes, if necessary, a detailed technical inspection of the involved vehicles. The DEKRA experts operate all over Germany on a 24 hour/7 day week basis. Consequently, the nearly 500 DEKRA accident experts have the opportunity to acquire all the information necessary for their task. The reports provide a substantial basis for accident research work. The DEKRA Accident Research and Crash Test Center has the opportunity to select and analyse interesting cases which normally consist of the written expert opinions, detailed accident reconstructions, sketches and photo material. Sometimes single injuries are described but by and large only the general injury severity is stated. The actual DEKRA PTW database comprises 350 cases from 1996 to 2005 with all kinds of other vehicles as well as single PTW accidents. About 300 parameters per accident are reviewed when using the DEKRA questionnaires. Since expert opinions are normally commissioned only when the accident is of a really serious nature, the main focus of the PTW database is directed towards accidents resulting in severely or fatally injured persons. These accidents happen mostly in rural areas and involve high speeds. Therefore, the outcome of each accident and the relevant impact velocities have to be interpreted under the circumstances mentioned above.

GIDAS database

GIDAS stands for “German In-Depth Accident Study” which is being carried out by two independent teams. The Hannover team is sponsored by BASt (Federal Highway Research Institute) while an industry consortium under the auspices of VDA/FAT is financing a second investigation team at the Technical University of Dresden. Both teams share a common data structure and the cases are stored in a single database. A random sampling scheme was introduced in August 1984 and is still in use. So 1985 is the first year for which this database can be considered representative of the German national statistics. Accidents are investigated at scene using blue-light response vehicles. In most cases extensive photo documentation is also available. The data cover the accident situation, participants (including cars, motorcycles, pedestrians/cyclists, trucks, buses, trams, trains), accident cause, injury cause, human factors and vehicle technologies. The qualifying criteria are that

- the road accident resulted in at least one person being injured,
- the accident occurred within specified regions around Hannover or Dresden,
- the accident occurred while the team was on duty (2 six-hour shifts per day, alternating on a weekly basis).

Approximately 2,000 new accident cases are investigated each year. The GIDAS 2002 dataset which was analysed for the several tasks within the exercise was purchased from DEKRA and relates to 230 powered two-wheelers and 248 PTW users.

COST 327 Database

The organisation European Co-operation in the Field of Scientific and Technical Research (COST) 327 was formed to investigate head and neck injuries suffered by motorcyclists by carrying out a comprehensive and detailed analysis. The COST 327 accident database consists of 253 cases collected from July 1996 to June 1998 in the UK by the Southern General Hospital, Glasgow, in Germany by the Medical School of Hannover and Munich University (LMU) and in Finland by the Road Accident Investigation Team. All cases are characterised by the following criteria:

- a powered two-wheeler was involved,
- a full or open face helmet was worn,
- head/neck injuries of AIS 1 or above were suffered – or known head/helmet contact without head injuries occurred.

Head injuries occurred in 67% of all cases. In 27%, a neck injury was sustained. The proportion of head injuries was considerably higher with MAIS 3 and above (81%) than with MAIS 1 (38%). The effect of climatic conditions on accident risk was investigated but found difficult to determine, however, due to the retrospective character of the study.

NL–MAIDS database

In order to better understand the nature and causes of PTW accidents, the Association of European Motorcycle Manufacturers (ACEM) with the support of the European Commission and other partners conducted an extensive in-depth study of motorcycle and moped accidents during the period 1999-2000. Sampling was carried out in five areas located in France, Germany, Netherlands, Spain and Italy, resulting in a large PTW accident database called after the MAIDS (Motorcycle Accident In-Depth Study) project. The methodology developed by the Organisation for Economic Co-operation and Development (OECD) for on-scene in-depth motorcycle accident investigations was used by all five research groups in order to maintain consistency in the data collected in each sampling area. A total of 921 accidents was investigated in detail, resulting in approximately 2,000 variables being coded for each accident. The investigation included

- a full reconstruction of the accident,
- detailed inspection of vehicles,
- interviews with accident witnesses,
- collection of factual medical records relating to the injured riders and passengers. These were subject to the applicable privacy laws and were obtained with the full cooperation and consent of both the injured person and the local authorities.

The in-depth data gathered in the Netherlands by TNO are part of the MAIDS database. In this part of the database 200 accidents were investigated and coded. The accidents incorporated were all PTW accidents in the Haaglanden region (The Hague, Rotterdam), in which a police alert was sent to the Dutch accident research team. The coverage was over 90% of all PTW accidents in the region. The accidents were accordingly put into two databases:

1. Database relating to the accident configuration, vehicle and rider/passenger information.
2. Database relating to injuries. Each injury is a separate data field and is assigned to a particular accident by means of the accident identification code. Only the rider injuries were considered in the investigation, because passenger injuries had not been included yet in the injury database.

PTW–Car accidents

Data from the national accident statistics of Germany from the years 1994 to 1999 were analysed in a study by ASSING in 2002 [4] in which the principal causes leading to PTW accidents were explored. In 11% of the cases the PTW user was responsible as a result of wrong road use, in 25% by failing to respect priority or to give way and in 42% by left or right turn manoeuvres. In the cases where a car was involved 34% of the incidents were caused by a priority/give-way violation. In 2004, HUANG & PRESTON stated that in many multi-vehicle crashes involving motorcyclists, the motorcycle was either not seen or seen too late by the other involved vehicles [5]. This has to do with the size of a motorcycle, which is rather small, and the fact that they are less frequently encountered in traffic situations. On the whole other drivers are not so accustomed to their presence on the roads as they are to cars. Other than that, car drivers who ride a motorcycle themselves or who relate in some way to motorcycle riders are less likely to collide with motorcyclists. In multiple vehicle crashes the other vehicle fails to give way in two thirds of the cases. The main scenario involves a motorcycle going straight ahead and a car turning left into a side road. In single vehicle crashes a pre-accident error contributed to the actual accident. ABS will improve the active safety of the motorcycle rider. Secondary safety devices like airbags and leg protectors will improve rider safety in most cases, but may have some negative side effects. A comprehensive PTW accident study on Dutch roads was published by KAMPEN & SCHOON in 2002 [6]. Regarding the direction of impact, in more than 60% of the cases the front side of the PTW was hit. Side impacts to the second vehicle occurred in approximately 35% of the motorcycle cases and 30% of the moped cases. In 1991 KAUTZ analysed 501 motorised two-wheeler accidents in the Dresden area in Germany. He found that in 41% of the cases the PTW user was responsible for the accident, 22% were single vehicle accidents and the opponent most frequently hit was a car [7]. In the accidents caused by motorcyclists, in 23% speeding was a contributing factor and in half of all accidents a failure to see the PTW by the driver of the car led to the accident. In the accidents where faults in driving manoeuvres were made, 44% of the riders had less than 2 years riding experience. Fatal motorcycle accidents in England and Wales have been analysed by LYNAM in 2001 [8]. Within those 717 accidents about 60% involved cars but where the motorcyclist was claimed to have caused the accident. In 44% the main contributing factor was speeding. Single vehicle accidents were mostly due to loss of control and travel speeds well above 40mph in rural areas. OSENDORFER & RAUSCHER mentioned in their

BMW C1 study that 42% of the analysed PTW accidents were frontal collisions and in half of the cases a car was the other vehicle involved [9]. In 1985 SIMARD examined more than 24,000 motorcycle accidents in the Quebec region in Canada and concluded that failure to give way was a major cause of severe motorcycle-car side impacts [10]. Furthermore, another typical accident cause involved a car driving well over on the right-hand side and then turning left while the motorcycle was overtaking. As far as collision types are concerned, SPORNER stated in his study from 1995 taking 528 motorcycle-car accidents into account, that the majority of the collisions could be categorised into 14 main collision types. The principle characteristic of these was that the front of the PTW (60% of the cases) hit the front of the passenger car. A front corner of the passenger car was hit in 45% of the cases. When considering the angle between the longitudinal axes of the vehicles, more than 50% of the cases were the result of an almost perpendicular side impact (23%) or of an opposing angled (frontal-oblique) impact (32%) [11]. In a recent study from BERG regarding national German data for 2002 a brief analysis on accident types is given. It is mentioned that 70% of the motorcycle crashes in urban areas (n=20,979) involved a passenger car as the second party. On rural roads (n=12,952) this was 46% [12]. A survey from OTTE in 1998 quoted that in 64% of the analysed events in German and UK national statistical data a car was the second involved party in PTW accidents [13].

In the in-depth databases the two-vehicle categories mofa/moped and motorcycle should have been analysed separately. After an initial inspection regarding the selected accident scenario distribution in the four databases (Table 2), it was decided to analyse all powered two-wheelers together because separation would have led to very small case numbers which had no statistical significance. The Dutch part of the MAIDS database is provided by TNO, the COST 327 database by LMU (Ludwig-Maximilians- University) and the appropriate abbreviations are used in Table 2.

Large differences are to be observed within the different databases. This is primarily related to the different data acquisition methods and their inclusion criteria. The only relatively high coincidence occurs in the case of urban areas with motorcycles impacting cars at intersections. In order to answer the question whether or not the PTW had the opportunity to brake before impact, the cruising speeds and the impact speeds are of interest in the case of a primary impact with the car. The possibility that the accident could have been avoided could be deduced from that information. The cruising and impact velocities were grouped into 25km/h bands and the cruising speed was cross-correlated to impact speed, Figure 2 to Figure 4. It can be seen that the impact speed is nearly always in the same band as the cruising speed. This does not mean that there was hardly any

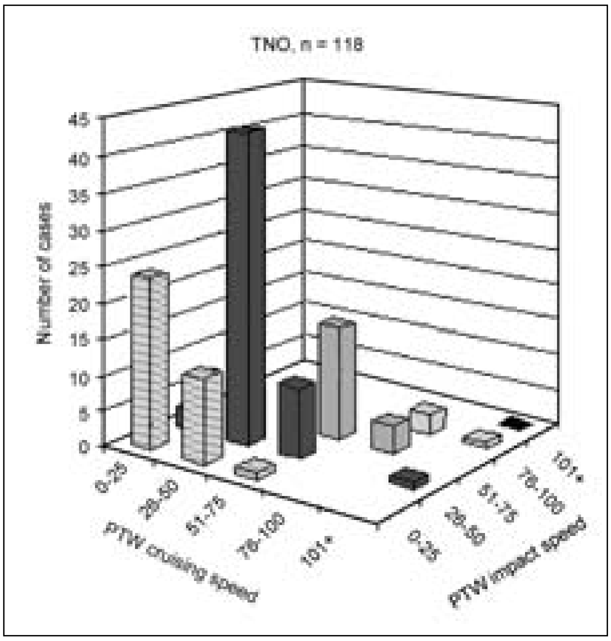


Figure 2: PTW cruising speed and impact speed, TNO MAIDS

	TNO n=85	DEKRA n=157	GIDAS n=128	LMU n=76
Urban – Moped – Car – Intersection	49%	5%	12%	4%
Urban – Moped – Car – Straight road	12%	1%	3%	1%
Urban – Motorcycle – Car – Intersection	21%	29%	55%	42%
Urban – Motorcycle – Car – Straight road	11%	11%	21%	22%
Rural – Motorcycle – Car – Intersection	4%	38%	3%	13%
Rural – Motorcycle – Car – Straight road	4%	16%	6%	17%

Table 2: Accident scenario distribution within the four databases

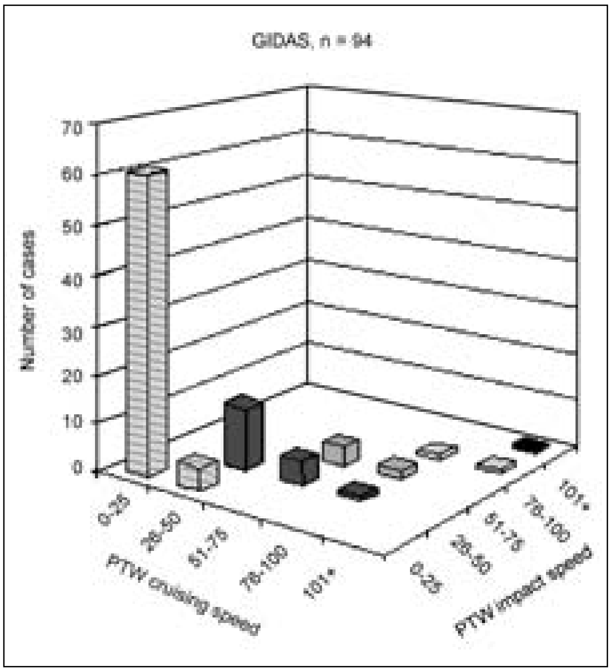


Figure 3: PTW cruising speed and impact speed, GIDAS 2002 data

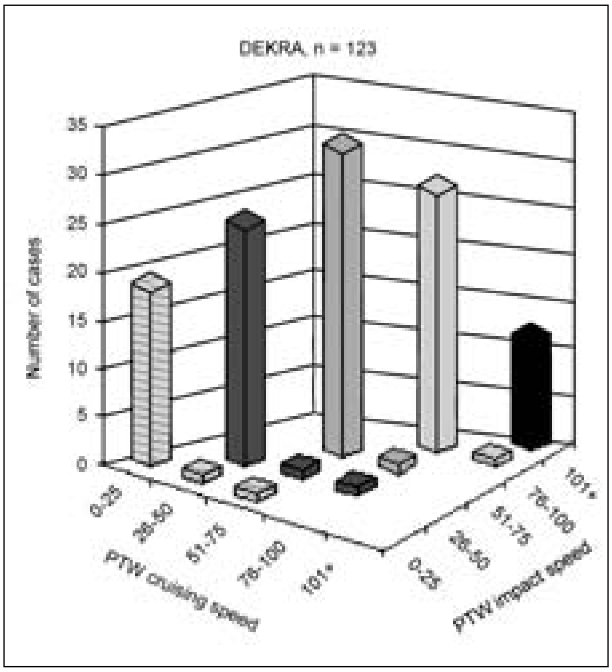


Figure 4: PTW cruising speed and impact speed, DEKRA data

speed reduction, but it does indicate that the speed reductions were not extremely high. The conspicuous high cruising and impact speeds in the DEKRA database are related to the fact that most of the severe and fatal accidents which are recorded are associated with the higher speed bands. It is possible to derive from each of the databases any accident avoidance manoeuvres that were attempted such as swerving, branking using both front and rear brakes or combined braking and swerving. Nevertheless in up to 94% of the analysed cases these actions were unsuccessful. This could often be a matter of timing, like such as braking too late or a matter of insufficient brake power due to wet roads or skidding.

PTW-to-car impacts with the PTW moving upright prior to the impact could be coded in the ISO 13232 format. This three digit code enabled a classification to be made of the contact points of the vehicles and their respective heading angle at the moment of first impact [14]. In most of the impacts the PTW was still upright and the rider was not separated from the PTW at the time of impact. This was true in typically 55% of the cases. ISO constellations could be directly gathered from the DEKRA database in which they are coded. For the TNO MAIDS database it was possible to assemble the data from the relative heading angle of PTW and car and the impact locations on PTW and car. The variety of impact constellations is substantial and they do not show a clear trend. However front-front and front-side PTW to car impacts are the most relevant ones, Figure 5. The next item to be considered is the type and severity of injuries suffered by the PTW user. In the databases from LMU and GIDAS, the lower extremities are hit most often, followed by the head, then the upper extremities and thorax. It should be noted that LMU data have the head-neck injury inclusion criterion so that the amount of injuries to that body region will be over-represented. Furthermore the lower extremities portion in the GIDAS data is very large. The object hit is primarily the car, followed by the road and the PTW. For the head and the neck there are few cases recorded where another object was hit. This could have been for instance a road-side structure, Figure 6 and Figure 7.

The injury severities reported from the GIDAS 2002 database are shown in Figure 8. The thoracic injuries are commonly not very severe when compared with the other databases. This is an unexpected result but it should be kept in mind that the head injuries in GIDAS are also relatively slight, whereas in the COST 327 database such injuries are extremely severe. This is related to the fact that the GIDAS database is representative according to the German National Statistics. Here, more than 68% of the PTW accidents occur in urban areas where the driving speeds are relatively low. The proportion of slightly injured PTW users (67%) is also representative in regard of the National Statistics.

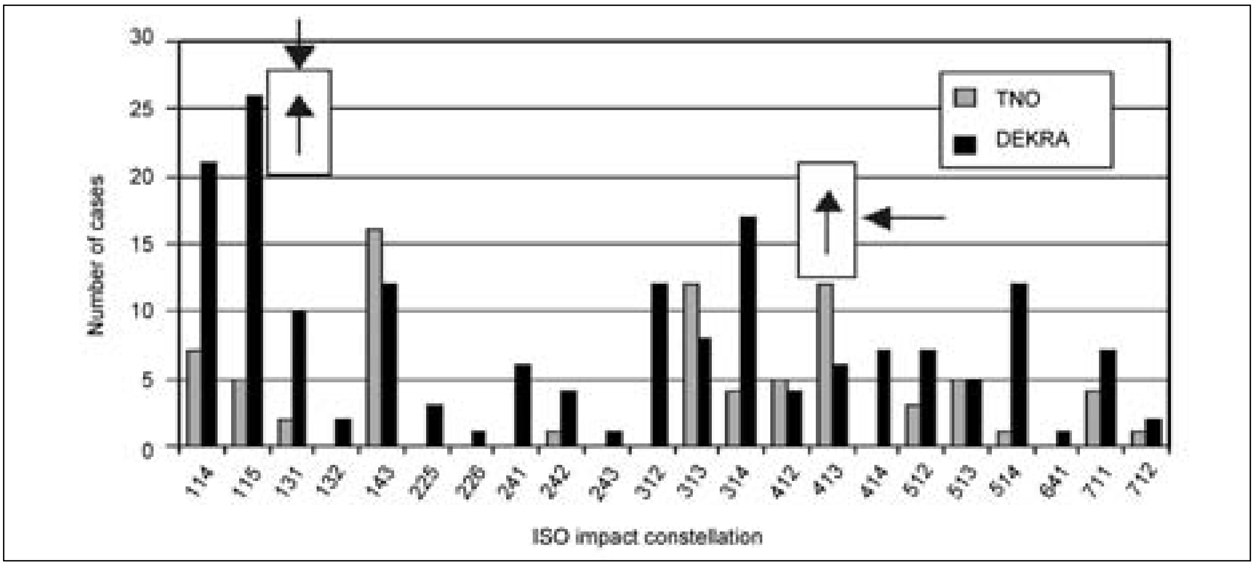


Figure 5: ISO impact constellations, TNO- MAIDS and DEKRA databases

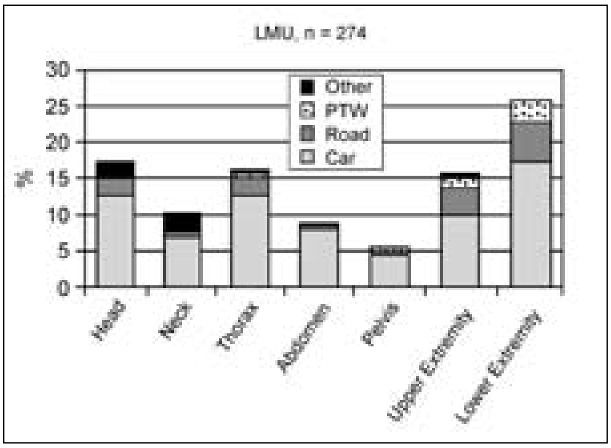


Figure 6: Primary body region affected by the impact, LMU COST 327 data

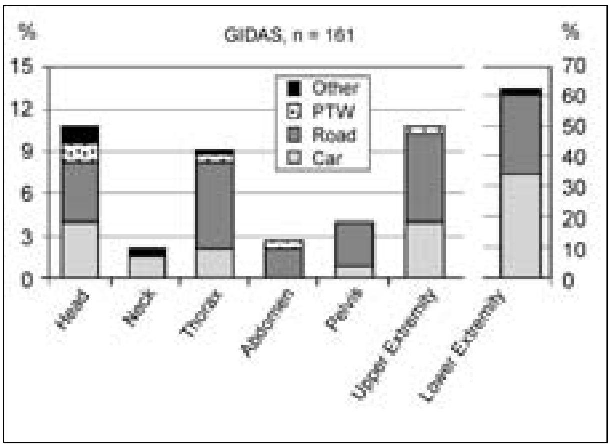


Figure 7: Primary body region affected by the impact, GIDAS 2002 data

The location where the rider finally ends up after the impact is called the rider point of rest (POR). This position is often very different from the point of impact (POI) and the distance between them can sometimes be quite large [15]. The ways in which this distance between POI and POR is covered can be very diverse and are coded differently in the databases used. The TNO data show a large number of throws, almost equal to the combined number of tumble/roll/skid types of transition, while the German LMU and DEKRA data contain a very large number of these tumble/roll/skid types of transition. Additionally the relation between POI and POR in regard to injury severity was analysed. It could be observed that contact with the car caused more severe injuries to head, abdomen and thorax, while the accidents with a large POI-to-POR distance have relatively more low-severity upper- and lower extremity injuries. When comparing

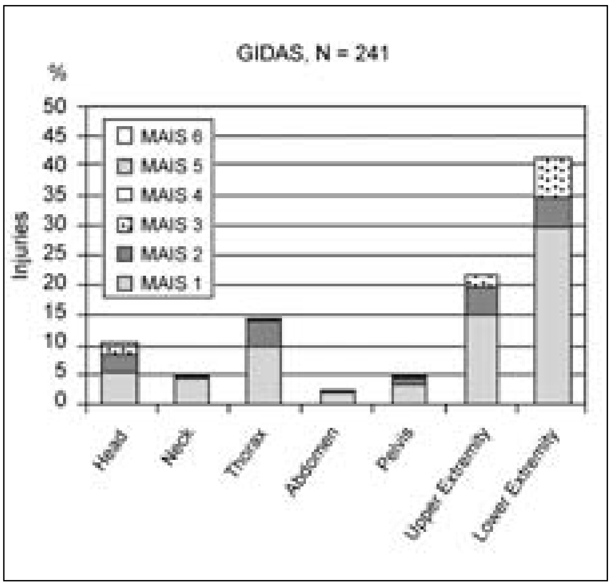


Figure 8: MAIS injury level with respect to specific body areas, GIDAS 2002 data

accidents with long POI-to-POR distances (>10m) with accidents with short POI-to-POR distances (<10m) it can be seen that in the short POI-to-POR distance accidents

- the injury is frequently caused by contact with the car;
- the injuries are more severe on average;
- head and abdominal injuries occur more often and are more severe;
- thorax injuries are more severe;
- upper and lower extremity injuries are less often encountered.

Concluding, the main cause of PTW accidents is related to perception failure. If the PTW user tries to avoid the accident, front and rear brakes are often applied, however, mostly without success. As a consequence the PTW hits the car, or the car hits the PTW with the rider seated in an upright position. The rider either hits the car first, resulting in severe head or abdominal injuries or ejects from the PTW, resulting in a vault or throw, the nature of which is dependent on the impact speed and impact constellation. As a consequence the road is hit in a secondary impact and the injuries relate mainly to the extremities, these being less severe than the injuries resulting from body impacts with the car.

PTW–infrastructure accidents

As already mentioned, the GIDAS 2002 data represent the whole accident situation in Germany. For that reason, most of the registered accidents occurred inside urban areas with relatively low impact speeds and – as a result of that – relatively low injury levels. Regarding the in-depth analysis of PTW-to-infrastructure accidents, very few cases are usually available. The GIDAS 2002 data comprise only 6 barrier and 3 tree or pole impacts. Therefore this section of the paper which focuses mainly on GIDAS database analysis only summarises briefly the main results of the overall exercise [16].

The most significant obstacles involved in accidents with a particularly severe outcome were trees/poles, roadside barriers and road infrastructure elements in general also including pavement. Analysis of the collision sequences indicates that most of the obstacle impacts took place as primary impacts. Accidents involving tree/pole impact seemed to be largely single-vehicle accidents [17]. Impact speeds in accidents involving roadside barriers as an obstacle tend to be very high, whereas impact speeds did not differ outstandingly from the whole group of accidents with a tree/pole involvement as a result of being in the median range of 30–40km/h for TNO and GIDAS and 50–60km/h for Cost 327 and DEKRA data. The angle at which a rider typically left the road seemed to be very shallow and the rider thereby seemed to be aligned nearly parallel to the road. In most impacts with trees/poles and barriers the rider was upright on his PTW. When a metal guar drail was struck, the rail seemed to be hit more often than the post. A small percentage of accidents involved road-infrastructure features. Causation issues can rarely be determined for different obstacles. The impression is gained that roadside barriers cause particularly severe injuries when hit. Taking into account the observed impact speeds, tree/pole impacts have to be considered to be at least as equally dangerous as barrier impacts. Obstacle impacts result in head injuries particularly often and when barrier impacts occur the lower extremities are injured nearly as often as the head.

PTW user protective devices

In order to obtain comparable data from the four different databases, a series of common charts was set up. The objectives of the analysis of these accident data records were the identification of the most frequently injured body region, the most severely injured body region, the typical injuries sustained by each body region and the verification of information about the performance of the motorcyclists' protective clothing. To reach a reliable conclusion from this analysis, it was decided to include all the accident scenarios in order to consider as many cases as possible. In a first step, a paired comparison between injured and uninjured motorcyclists was conducted. In this way the possible influence of the protective clothing worn could be derived. Additionally, the different kinds of injuries to each specific body region were analysed separately, enabling valuable conclusions to be drawn about how the protective elements should work to be most effective in the prevention of injuries. Three different impact speed ranges (0-35km/h, 36-70km/h and >70km/h) have been analysed with respect to different protective clothing combinations. This led to a primary overview of the miscellaneous protection levels in the four databases. The definition of protection level is given in Table 3. As expected, the helmet was the most frequently used item of protective clothing and therefore protection level 1 was the level achieved most often, namely by an average of 66% of the PTW users. The second most frequently achieved protection level according to the databases was level 3 by a mean of 18% of the PTW users. As far as trousers, jackets and boots are concerned it was considered that only clothing made out of leather or special heavy garment material like Kevlar or imitation leather was able to offer any protection.

By relating the previously mentioned protection levels found in the four different in-depth databases to the severity of injuries suffered by the respective riders and passengers, it could be stated that in general injury severity decreases with increasing level of protection, see Table 4. However, this is not true for level 0 where only 27 cases were available.

For the three different speed bands the rider and passenger related injuries have been further investigated and classified by means of the Abbreviated Injury Scale (AIS) coding. At speeds up to 35km/h, it was noted that only the head sustained severe injuries (AIS 3+) according to the NL-MAIDS and GIDAS 2002 data. From the COST 327 information, it was clear that the thorax and abdomen also sustained severe, critical or maximum injuries. Additionally, with an increase of impact speed, other body regions were severely injured. Particularly the spine and neck injuries were already at a critical level for the speed band of 36-70km/h. The pelvis as well as the upper extremities sustained severe injuries when the impact speed exceeded 35km/h. For the impact speed band of 36-70km/h, the corresponding impact points struck by the riders and passengers as recorded in the NL-MAIDS and the GIDAS 2002 database are shown in Figure 9. In most body regions, impact with the ground or road as well as impact against an unspecified object were considered to be responsible for the injuries. Regarding pelvic injuries it is worth mentioning that often the PTW itself (e.g. the fuel tank, handlebar, etc.) was the object responsible for causing injury.

The body regions suffering injury have been analysed separately. For the head, helmeted and un-helmeted riders and passengers have been compared in order to identify possible protection effects. Different helmet types such as full-face helmet, jet helmet and half-shell helmet have been analysed within the three impact speed bands. The data showed that a significant number of riders did not use a helmet. This is due to the fact that in the Netherlands a helmet is not compulsory for low-speed mopeds. Compared to the un-helmeted PTW users those wearing a helmet suffered lower injury severity levels. This is true for all impact velocities. For impact speed values up to 35km/h, the helmet was effective in preventing severe injuries while, as soon as the impact speed values increased, the number and the severity of different types of injuries increased too. Additionally the helmet situation was split into 18 sectors and the damage to each of

Protection Level	Clothing combination	Protection Level	Clothing combination
0	No protection	1	Helmet
	Jacket		Helmet and boots
	Trousers		Helmet and gloves
	Jacket and trousers		Helmet and trousers
	Jacket, trousers and boots		
2	Helmet, gloves and boots	3	All the body covered
	Helmet, jacket and boots		Helmet, jacket and trousers
	Helmet, jacket and gloves		Helmet, jacket, trousers and boots
	Helmet, jacket, gloves and boots		Helmet, jacket, trousers and gloves

Table 3: Protection levels and respective clothing combinations

Protection level	Number of cases	Not injured	Slightly injured	Severely injured	Killed
0	27	3.7%	55.6%	33.3%	7.4%
1	586	1.9%	19.6%	39.8%	33.3%
2	102	0.0%	31.4%	36.3%	32.4%
3	159	1.9%	37.1%	32.1%	28.9%

Table 4: Injury distribution in relation to protection level

those as well as the corresponding injuries were analysed. It was found out that the critical regions were the forehead and the rear part of the helmet. Loss of the helmet during the impact was found not to be an unusual event. Improvements to the strap and/or the fitting of the helmet to the head were classified as effective countermeasures.

For facial injuries only NL-MAIDS and GIDAS 2002 data were taken into account because in the COST 327 database these injuries are included in the head section. Here, too, the different helmet types and the impact speed ranges have been considered. Again, it was found that the helmet is capable of preventing injuries, although it was

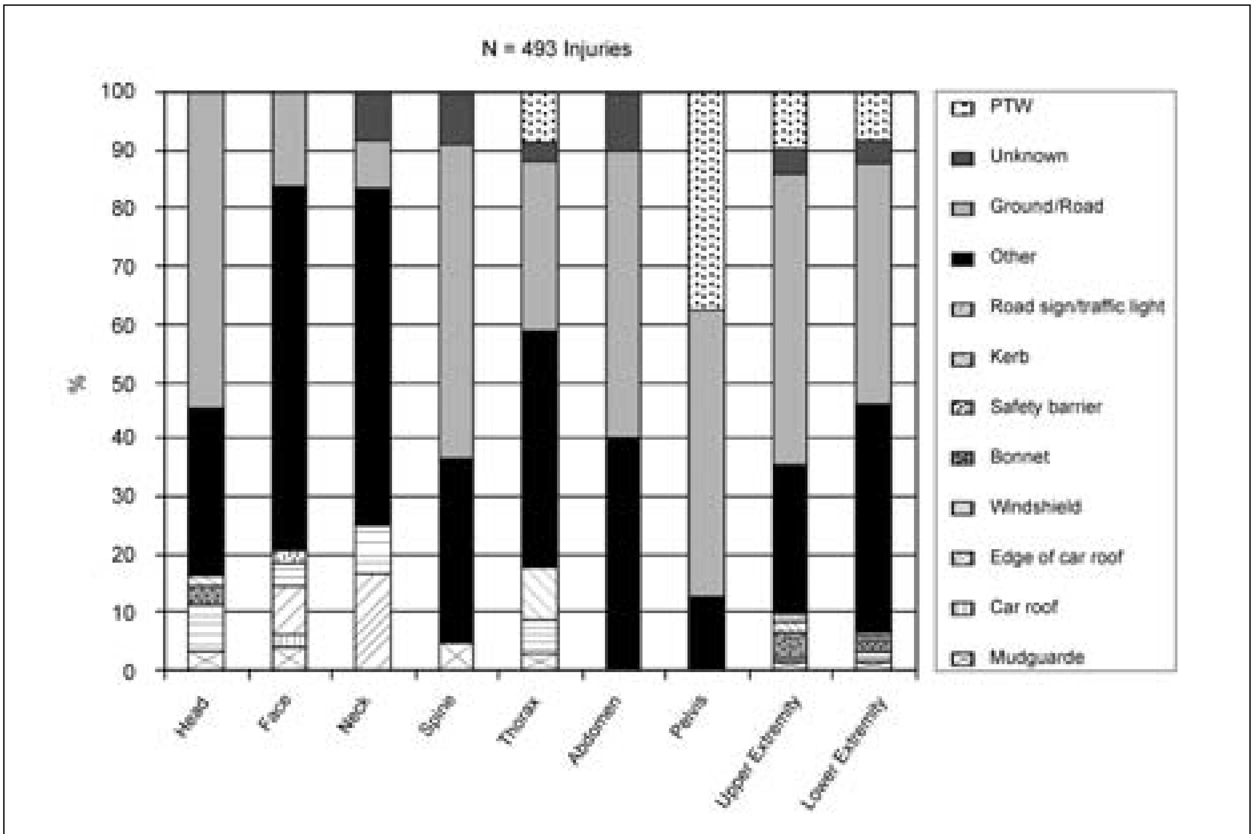


Figure 9: Spread of injuries and related impact locations for the impact speed band 36-70km/h, according to NL-MAIDS and GIDAS 2002 data

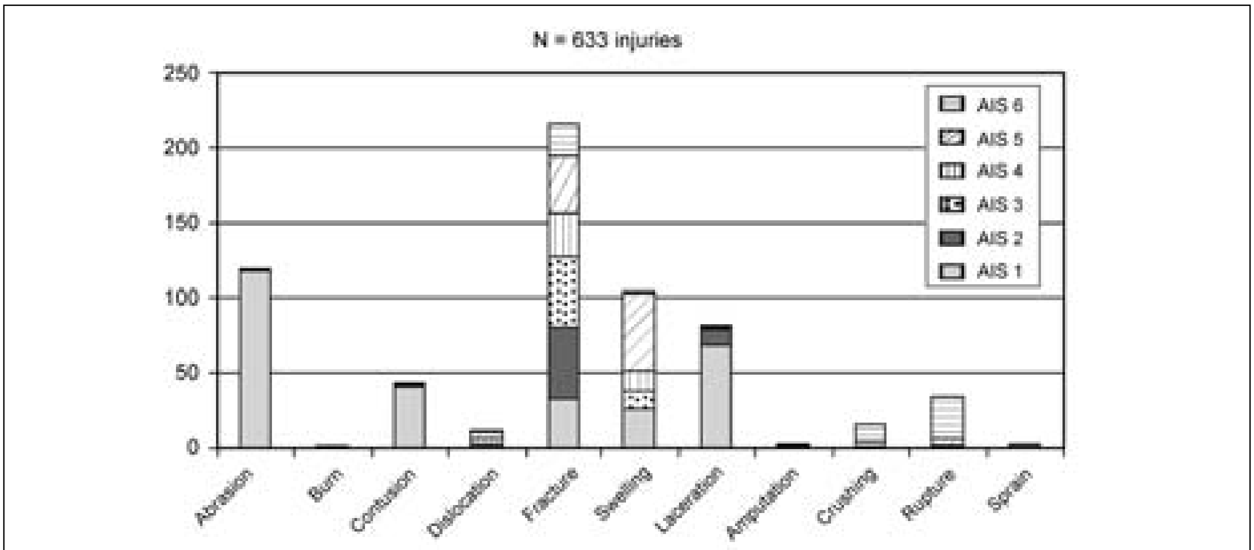


Figure 10: Injury types and severity levels for the neck, COST 327 database

noted that regardless of the impact speed the recorded AIS levels for the face were very low. They consisted mostly of abrasions, contusions and lacerations.

As far as the neck is concerned in NL-MAIDS and GIDAS 2002 databases, only the soft tissue injuries have been taken into account. The more severe skeletal injuries have been analysed separately in the spine section. Because of this, neck injury severity levels recorded in NL-MAIDS and GIDAS 2002 are lower than those found in COST 327 cases. The likelihood of soft tissue injuries in the neck is very low. In the case of COST 327 data where skeletal injuries were also included, the frequency and severity of neck injuries increased significantly for impact speeds higher than 35km/h. The different kind of injuries to the neck found in the COST 327 database are shown in Figure 10. Mostly AIS 1 injuries were recorded which normally refer to soft tissue injuries such as abrasions, lacerations or contusions. The severe neck injury types (AIS 3+) consisted of dislocations, fractures, swelling, crushing, and rupture.

Protected – meaning the wearing of leather clothes or heavy garments – and unprotected PTW casualties have been compared for their influence upon injury to the upper extremities. From the GIDAS 2002 and NL-MAIDS data, it can be seen that the frequency with which injuries to the upper extremities were sustained was reduced when protective clothing was worn, regardless of the impact speed. From the analysis of COST 327 data a similar situation is obtained, except for the impact speed band of 36km/h to 70km/h. No matter what impact speed or what database was taken into account, it can be stated that wearing protective clothing seemed to reduce the level of injuries. In fact, comparing casualties to injuries, 74 injuries were recorded for 51 harmed protected riders whereas 152 injuries emerged for 89 unprotected riders. The same analysis has been performed for the COST 327 data which respectively showed a total amount of 66 injuries for 46 injured protected riders against 169 injuries for 109 unprotected hurt riders. As far as the distribution of injury severity is concerned, it can be stated that the use of motorcyclist protective clothing had some benefits particularly at impact speeds up to 35km/h. The most common injury types were abrasions, fractures and contusions.

Almost the same conclusions could be drawn for the lower extremities as for the upper extremities. Wearing rider protective clothing significantly reduced the amount and the severity of injuries sustained at all impact speeds. For 49 wounded protected riders 85 injuries were recorded whereas for the unprotected riders 160 casualties with 331 injuries arose (NL-MAIDS and GIDAS 2002). The same trend was illustrated by the COST 327 data which showed a total of 59 injuries for 43 injured protected riders while 297 injuries were recorded for 161 unprotected harmed riders. The most frequent types of injuries were contusions, abrasions and fractures.

Analyses dealing with spinal injuries demonstrated that motorcyclist protective clothing is helpful in reducing the injury severity and the number of injuries in comparison to the number of casualties in all speed bands. Although there are not many cases available from GIDAS 2002 and Dutch MAIDS data, this trend could also be observed here – 18 injuries were recorded for 17 injured protected PTW users whereas 19 injuries were sustained by 14 harmed PTW users. The most frequent of the spinal injuries were fractures and distortions in the cervical spine area.

The data concerning thorax injuries confirmed that contusions and fractures in that order were the most frequent injuries. With regard to injury severity, damage to internal organs was the most critical aspect. From COST 327 data also, fracture was found to be one of the most severe types of injury but in this case, the data also included spinal injury and this affirmed the outcome of the previous section relating to the spine.

Summary and Future Steps Action

In order to reach the ambitious target to cut in half the number of road users killed every year by 2010 (based on the 2001 figures) for the EC-15 countries, special attention must also be paid to PTW accidents. Consequently, a sub-project dealing with motorcycle accidents was established within the APROSYS IP of the 6th Framework Programme of the EC. A two-step investigation of the PTW accident records has been completed. The National Statistics of four European countries for the years 2000–2002 have been analysed and found to show similar trends for the specific matters of concern which were examined. Seven main PTW accident scenarios were identified which have been further investigated via in-depth databases. The analyses of these scenarios have been conducted by making use of the DEKRA PTW database, the GIDAS 2002 database, the COST 327 database and the Dutch element of the MAIDS database:

Urban – Moped – Car – Intersection.

Urban – Moped – Car – Straight road.

Urban – Motorcycle – Car – Intersection.

Urban – Motorcycle – Car – Straight road.

Non-urban – Motorcycle – Single vehicle accident.

Non-urban – Motorcycle – Car – Straight road.

Non-urban – Motorcycle – Car – Intersection.

In a subsequent step, three different tasks have been set up dealing with PTW-to-car accidents, PTW collisions with infrastructure features and the performance of rider protective devices. For the PTW–car accidents it was found that the outcomes of former studies in the field could be endorsed. Most PTW-to-car accidents resulted from a perception failure. As far as the ISO 13232 impact constellations are concerned, it was possible to confirm front-front and front-side impacts of the PTW with the car as being the most frequent. Accident avoidance manoeuvres on the part of the PTW were sometimes accomplished through braking and/or swerving but with little success. On average, injuries suffered by the PTW users were more severe when caused by contact with the car. In the case of PTW collisions with infrastructure features the most significant obstacles involved in accidents with a particularly severe outcome were trees/poles, roadside barriers and road infrastructure features in general including pavement. Frequently the collision with a road infrastructure feature constituted the primary impact. Roadside barriers appeared to cause particularly severe injuries when struck, a noteworthy point here being that the impact angles were rather shallow. Obstacle impacts led to head injuries particularly often and the lower extremities were injured nearly as often as the head. For the determination of the effectiveness of protective devices used by PTW drivers, a paired comparison between protected and unprotected casualties has been carried out in which four protection levels were defined. The analyses were focused on the impact speed bands of 0-35km/h, 36-70km/h and exceeding 70km/h. Even at velocities up to 35km/h, it was noted that the head, thorax, pelvis, abdomen and the upper extremities sustained severe, critical or maximum injuries. Analyses of spinal injuries demonstrated that motorcyclist protective clothing is helpful in reducing both the injury severity level and the number of injuries which are sustained in accidents occurring in all speed bands.

In the next stage of the project which deals mainly with PTW collisions with infrastructure features and the evaluation of rider protective devices, in-depth data as well as real crash test data will be further investigated. In particular, rider and PTW kinematics prior to, at the time of and after the collision are to be determined. Parameters such as impact angles, trajectories, POI-to-POR distance etc. will be gathered on a case-specific basis in order to define a model scenario. This model scenario will be reconstructed and visualized using multi-body simulation tools. Injuries will be simulated via human body models such as PAM Crash and RADIOSS. The output of the simulations will then be compared with the real accident data sets so as to validate the fitness of the simulations. Furthermore, a proposal for a test procedure to evaluate metal barriers will be developed as well as a concept design for motorcyclist safety in the context of roadside infrastructure features. Additionally, the problem of providing improvements to motorcyclist safety helmets and protective clothing will be addressed. Data relating to vehicle motion and impact behaviour will be studied in order to define working and activation parameters for complementary safety devices.

References

[1] FP6 APROSYS SP4: Deliverable D4 – 1 – 1, Public Report, 2005

[2] Annual statistical report: the SafetyNet Consortium, February 2005

[3] FP6 APROSYS SP4, Deliverable D4 – 1 – 2, Public Report, 2006

[4] K. ASSING (2002): Schwerpunkte des Unfallgeschehens von Motorradfahrern. Bundesanstalt für Straßenwesen, Mensch und Sicherheit, Heft M 137

[5] B. HUANG, J. PRESTON (2004): A literature review on motorcycle collisions. Final report, Oxford University

[6] L.T.B. KAMPEN, C.C. SCHOON (2002): Tweewielerongevallen (Two-wheeler accidents). SWOV report R-2002-5

[7] A. KAUTZ (1991): Statistical Analysis of motorcycle accidents in Dresden. Proceedings of the 1991 International Motorcycle Conference. Pp 107-115 (IFZ No. 7)

[8] D. LYNAM, J. BROUGHTON, R. MINTON, R.J. TUNBRIDGE (2001): An analysis of police reports of fatal accident involving motorcycles. TRL Report 492

[9] H. OSENDORFER, S. RAUSCHER (2001): The development of a new class of two-wheeler vehicles. Proceedings of the 17th ESV Conference

[10] B. SIMARD (1985): Quelques aspects des accidents de motocyclettes survenus au Québec entre 1980 et 1983. Proceedings of Canadian Multidisciplinary Road Safety Conference IV. Pp 476-488

[11] A. SPORNER, J. POLAUKE, J. van DRIESSCHE (1995): Collision Parameters from real-life car/motor cycle accidents. A basis for future standards. SAE paper 950203

[12] F.A. BERG, P. RÜCKER, J. KÖNIG (2004): Motorcycle crash tests – an overview. ICRASH 2004 Conference Paper

[13] D. OTTE, H. WILLEKE, N. CHINN, D. DOYLE, E. SCHULLER (1998): Impact mechanisms of helmet-protected heads in motorcycle accidents. Accidental study of COST 327. Proceedings of the 1998 International Motorcycle Conference. Pp 83-109 (IFZ No. 8)

[14] ISO 13232-2:1996 Motorcycles: Test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles – Part 2: Definition of impact conditions in relation to accident data

[15] A. SPORNER: Elemente eines Sicherheitsmotorrades. Motorradforum “Faszination und Sicherheit”, Querschnitt durch die aktuelle Motorrad-Sicherheitsforschung. Institut für Zweiradsicherheit e. V., Köln (1988)

[16] FP6 APROSYS SP4: Deliverable D4 – 1 – 3, Public Report, 2006

[17] F.A. BERG, P. RUECKER, M. GAERTNER, J. KOENIG, R. GRZEBIETA, R. ZOU (2005): Motorcycle Impacts into Roadside Barriers – Real-World Accident Studies, Crash Tests and Simulations Carried out in Germany and Australia. Proceedings of the 19th International Technical Conference on the Enhanced Safety of Vehicles

S.N. Huang, J.K. Yang
Division of Vehicle Safety, Chalmers University of Technology, Göteborg, Sweden

F. Eklund
Automotive Safety Electronics, Autoliv Electronics AB, Linköping, Sweden

Analysis of Car-Pedestrian Impact Scenarios for the Evaluation of a Pedestrian Sensor System Based on the Accident Data from Sweden

Abstract

There is a need for detecting characteristics of pedestrian movement before car-pedestrian collisions to trigger a fully reversible pedestrian protection system. For this purpose, a pedestrian sensor system has been developed. In order to evaluate the effectiveness of the sensor system, the in-depth knowledge of car-pedestrian impact scenarios is needed.

This study aims at the evaluation of the sensor system. The accident data are selected from the STRADA database. The accident scenarios available in this database were evaluated and the knowledge of the most common scenarios was developed in terms of the pedestrian trajectory, the pedestrian speed, the car trajectory, the car velocity, etc. A mathematical model was then established to evaluate the sensor system with different detective angles. It was found that in order to detect all the pedestrians in the most common scenarios on time the sensor detective angle must be kept larger than 60 degrees.

Notation

V_p pedestrian speed

V_c car velocity

T_r latency of the sensor and protection system

D_p walking distance of the pedestrian within the latency of the sensor and protection system

Y_c Y-coordinate of the collision point

Y_p Y-coordinate of the pedestrian

D_c critical reaction distance of the sensor and protection system

α half detection angle of the sensor system

D_s detection distance of the sensor system

P probability of the pedestrian being detected on time by the sensor system

1 Introduction

In order to trigger a fully reversible pedestrian protection system on time, an active sensor system was developed by Autoliv to detect and identify the pedestrian moving characteristics before car-pedestrian collisions. In order to evaluate the effectiveness of this sensor system, an in-depth analysis of car-pedestrian impact scenarios is needed. Some correlative researches have been carried out for different purposes. SCHOFER et al. (1995) presented a simple four-category taxonomy of child pedestrian-motor vehicle accidents and tested the effectiveness of this classification by using objective data and the results of causal sequence reconstruction [1]. STUTTS et al. (1996) applied the NHTSA pedestrian crash-typing system to categorize 5000 pedestrian-motor vehicle collisions reported by the U.S. police [2].

The present study aims to evaluate the sensor effectiveness for pedestrian detection. For this purpose, two goals were achieved. The first one is to develop the qualitative and quantitative knowledge of car-pedestrian accident scenarios indicated in Table 1. The second goal is establishing a mathematical model to evaluate the sensor system.

2 Material and Method

The main data source of this study is the Swedish Traffic Accident Data Acquisition (STRADA) [3]. The car-pedestrian impact scenarios in this database were evaluated by the statistical analysis of the selected accident data and the two most common scenarios were chosen for the sensor evaluation.

Qualitative Knowledge (Description)	Pedestrian Trajectory
	Passenger Car Trajectory
Quantitative Knowledge (Distribution)	Pedestrian Speed
	Passenger Car Velocity
	Location of Collision Point on Car

Table 1: Qualitative and quantitative knowledge of car-pedestrian accident scenarios

The qualitative and quantitative knowledge indicated in Table 1 was developed for these scenarios. Using the developed knowledge, the mathematical model was established and the sensor system was then evaluated by this model.

2.1 Data collection

STRADA is a database belonging to the Swedish Road Administration (SRA). This database has been under development since 1996 and stores road accident data from police and some hospitals. From January 1st 2003, all the police stations and approximately 50% of the emergency hospitals report traffic accidents to STRADA. The accident data in this report come from the police records from January 1st, 1999 to September 13th, 2005. From the total 5673 passenger car-pedestrian impacts, 2097 impacts between a single passenger car and a single pedestrian with the identified STRADA car-pedestrian accident scenario, as shown in Figure 1 and explained in Table 2, were selected.

Scenario	Description
F1	Pedestrian crossing road; passenger car coming from the left side of pedestrian
F2	Pedestrian crossing road; passenger car coming from the right side of pedestrian
F3	Pedestrian going along the left side of road
F4	Pedestrian going along the right side of road
F5	Pedestrian crossing before intersection; passenger car going straight forward
F6	Pedestrian crossing after intersection; passenger car going straight forward
F7	Pedestrian crossing after intersection; passenger car turning left
F8	Pedestrian crossing after intersection; passenger car turning right
F9	Pedestrian standing on the path of coming vehicle

Table 2: Description of the accident scenarios

2.2 Knowledge development

In the two most common car-pedestrian impact scenarios, the moving trajectories of the pedestrians and passenger cars were obtained directly from the definition of the scenarios. But the pedestrian speeds, the passenger car velocities and the locations of the body collision points on the cars are not recorded in STRADA. Therefore, the missed quantitative knowledge was estimated from the directly recorded information about the pedestrian ages, the road speed limits of the accident spots and the passenger car damages.

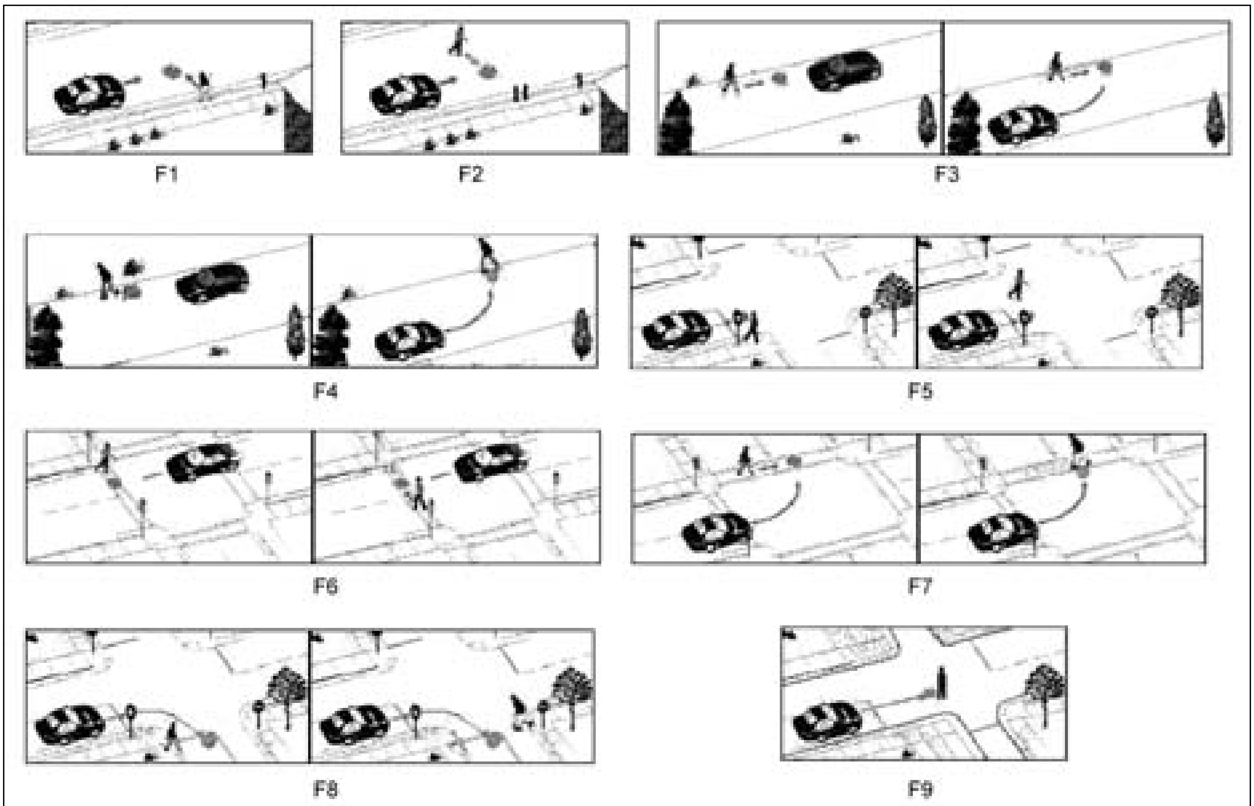


Figure 1: Passenger car-pedestrian impact scenarios in STRADA

2.2.1 Estimation of the pedestrian speeds

In the STARDA database, the pedestrian moving postures, such as walk or run, were not recorded. As a result, the pedestrian speeds were respectively estimated based on the hypothesis that all the pedestrians were impacted by cars while walking or the hypothesis that all the pedestrians were hit while running.

In the book "Pedestrian Accident Reconstruction and Litigation", the relationship between the pedestrian walking speed and the pedestrian age has been presented, as shown in Table 3 [4]. According to this relationship, the pedestrian walking speeds in the two accident scenarios were estimated.

In each of the scenarios, it was considered that the walking speeds of the pedestrians in each of the age groups listed in Table 3 should distribute in a normal distribution. The mean of this normal distribution was the 50th% speed for the age group. The standard deviation was calculated from the corresponding 15th% and 85th% speed. Using the speed normal distributions of the pedestrians in different age groups, the average 15th%, 50th% and 85th% speed of all the pedestrians were obtained by solving the equation below.

Pedestrian Age	Sample Size	Speed (m/s)		
		15th%	50th%	85th%
5-9	26	1.40	1.83	2.41
10-14	37	1.37	1.68	2.10
15-19	47	1.46	1.65	2.07
20-24	65	1.40	1.62	1.86
25-34	70	1.46	1.62	1.98
35-44	67	1.34	1.62	1.95
45-54	73	1.31	1.52	1.74
55-64	90	1.28	1.46	1.68
65+	67	1.07	1.28	1.46

Table 3: Pedestrian walking speeds for the different age groups

Pedestrian Age	Sample Size	Speed (m/s)		
		15th%	50th%	85th%
5-9	332	3.11	3.94	4.80
10-19	718	3.51	4.20	4.96
20-29	134	2.80	3.54	4.24
30-39	204	2.68	3.35	3.81
40-49	138	2.41	2.90	3.44
50-59	35	2.38	2.83	3.20
60+	30	2.04	2.47	2.71

Table 4: Pedestrian running speeds for the different age groups

$$N_t \times Per = \sum_{i=1}^{9} N_i \times Normdist(V_{per}, \mu_i, \sigma_i) \qquad (1)$$

Where N_t is the total number of the STRADA pedestrians; Per is percentage of the speed (15%, 50% or 85%); N_i is the number of the STRADA pedestrians in the ith age group in Table 3; Normdist is the cumulative normal distribution function of the pedestrian walking speed for the ith age group; V_{per} is the speed needed to be solved (the average 15th%, 50th% or 85th% speed); μ_i is the mean of the normal distribution and μ_i is the standard deviation of the distribution. It was then hypothesized that the walking speeds of all the pedestrians should also distribute in a normal distribution. The mean was chosen as the average 50th% speed and the standard deviation can be calculated from the average 15th% and 85th% speed. At last, a Chi-square test was used to validate this hypothesis.

Also in this book, the correlation between the pedestrian running speed and the pedestrian age, as indicated in Table 4 [4], has been researched. By the same method introduced above, the running speeds of the pedestrians in the two scenarios were estimated and validated.

2.2.2 Estimation of the car velocities

In the report "Speeds and Time Gaps", the car velocity relative to the road speed limit was investigated, as shown in Table 5 [5]. By the same method introduced in 2.2.1, the normal distributions of the car velocities in the most common accident scenarios were estimated and validated.

2.2.3 Estimation of the collision point locations

In the STRADA database, the car damage cases are distinguished with each other by the damage locations. If it is hypothesized that each damage case corresponds to a body collision point on the car, the locations of all the collision points can naturally be obtained.

Speed Limit (km/h)	Velocity (km/h)		
	2.5th%	50th%	97.5th%
30	29.3	34.5	39.7
50	51.0	52.4	53.8
70	67.3	68.4	69.5
90	87.9	88.9	89.9
110	110.2	111.4	112.6

Table 5: Car velocities with road speed limits

2.3 Establishment of the mathematical model

In this study, the sensor detective angle is a parameter which is already known. The shortest period from the pedestrian being detected by the sensor system to the protection system being totally deployed is another known parameter and is named the latency of the sensor and protection system. For each accident in the two most common scenarios, at the time of the latency period before the moment when the accident took place, the locations of the car and the pedestrian relative to the collision point can be calculated by their velocities and trajectories. Using the car location and the sensor detective angle, the sensor detective area on the pedestrian trajectory can be calculated. If this area covers the pedestrian, the sensor can detect the pedestrian on time. If not, the pedestrian will be missed by the sensor. While evaluating the sensor effectiveness in a whole accident scenario, the random distributions of the pedestrian speeds and car velocities can be used in the calculation. The obtained detective area and pedestrian location are also random variables. Using the density functions of them, the effectiveness of the sensor system can be calculated.

2.4 Sensor evaluation

Using the mathematical model, the sensor effectiveness for pedestrian detection was evaluated in the most common accident scenarios in terms of the different sensor detective angles. In this evaluation, it was hypothesized that all the pedestrians in the accident scenarios came from the right sides of the passenger cars. For each sensor detective angle, the evaluation was carried out respectively based on the hypothesis that all the pedestrians were impacted by cars while walking or the hypothesis that all the pedestrians were hit while running.

3 Results

3.1 Evaluation of the accident scenarios

Figure 2 shows the distribution of the nine passenger car-pedestrian impact scenarios. As indicated by it, F6 is the most common one. In this scenario, there are 647 car-pedestrian impacts which happened. They have occupied 30.9% of all the 2097 selected cases. In these accidents, 23 pedestrians were killed, 185 were seriously injured

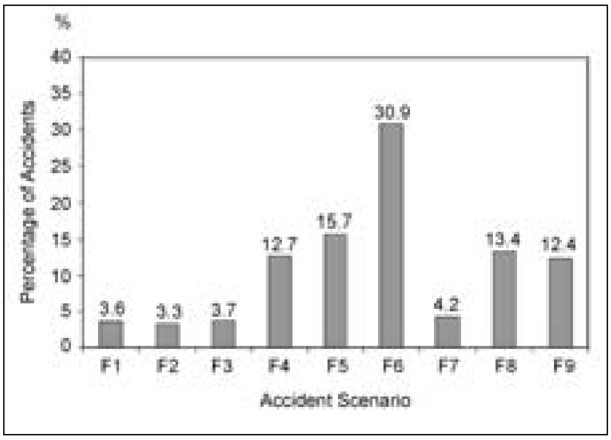


Figure 2: Distribution of the accident scenarios

and 439 were slightly injured. F5 is the second most common scenario. In this scenario, 329 passenger car-pedestrian impacts were recorded, accounting for 15.7% of all the 2097 accidents. In these accidents, 3 pedestrians were killed, 80 were seriously injured and 246 were slightly injured.

Because F5 and F6 are the most common accident scenarios, the qualitative and quantitative knowledge was developed just for them.

3.2 Knowledge development based on the accident scenarios

3.2.1 Moving trajectories of the pedestrians and cars

According to the classification of the accident scenarios in STRADA, the moving trajectories of the pedestrians and cars were obtained directly. In these two scenarios, the moving trajectories of the pedestrians and passenger cars are straight and vertical to each other.

3.2.2 Pedestrian speeds

Figure 3 shows the age distributions of the pedestrians in F5 and F6.

As can be seen, 12.2% of the pedestrians in F5 and 17.8% in F6 are children (0<age<=14). 87.8% of the F5 pedestrians and 82.2% of F6 are adults.

If it was hypothesized that all the pedestrians in F5 and F6 were impacted by car while walking, the speed distributions of the pedestrians more than 4 years old, as shown in Table 6, were found by the method introduced in 2.2.1.

When it was hypothesized that all the pedestrians were hit while running, the speed distributions of

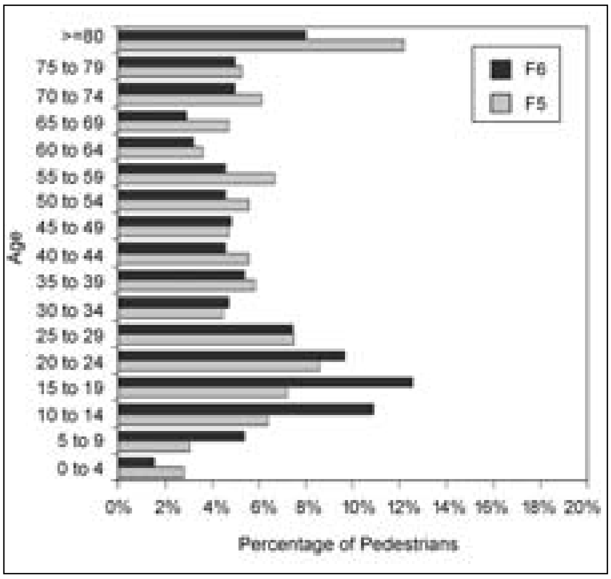


Figure 3: Distributions of the pedestrian ages

Accident Scenario	Mean (m/s)	Standard Deviation (m/s)
F5	1.48	0.29
F6	1.53	0.30

Table 6: Normal distributions of the pedestrian walking speeds

Accident Scenario	5-39 years old		Older than 40 years	
	Mean (m/s)	Standard Deviation (m/s)	Mean (m/s)	Standard Deviation (m/s)
F5	3.70	0.76	2.60	0.42
F6	3.80	0.78	2.61	0.42

Table 7: Normal distributions of the pedestrian running speeds

the pedestrians older than 4 years, as shown in Table 7, were respectively developed in two age groups of 5 to 39 years old and more than 40 years old so that they can pass the Chi-square test.

Validated by the Chi-square test, the normal distributions of the pedestrian speeds can be accepted on the significance level of 0.05.

3.2.3 Car velocities

As introduced in 2.2.2, the distributions of road speed limits, as shown in Figure 4, were used to estimate the car velocities in the accident scenario F5 and F6.

Based on Figure 4 and Table 5, the normal distributions of the car velocities in F5 and F6 were established, as indicated in Table 8. Validated by the Chi-square test, the normal distributions can be accepted on the significance level of 0.05.

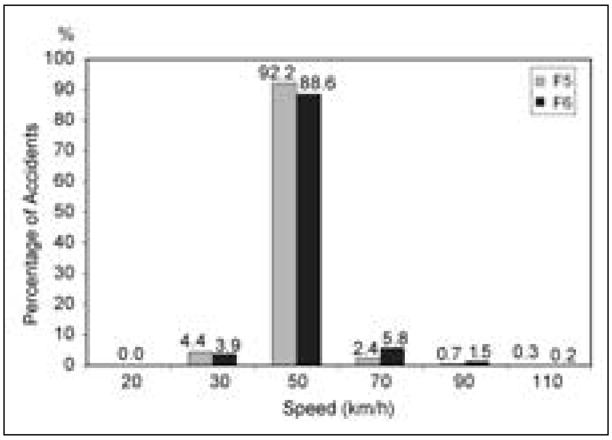


Figure 4: Distributions of the road speed limits

Accident Scenario	Mean (m/s)	Standard Deviation (m/s)
F5	52.4	8.5
F6	52.4	8.6

Table 8: Normal distributions of the passenger car velocities

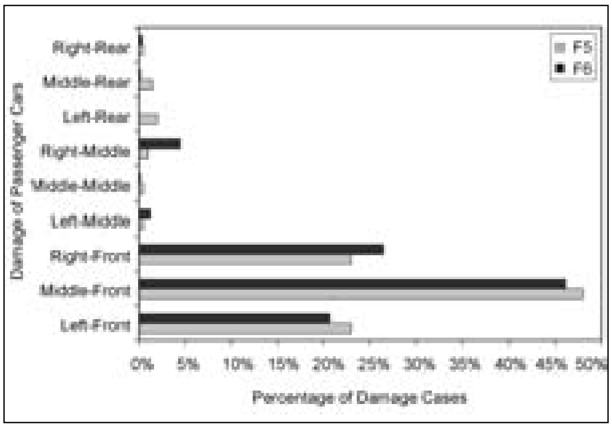


Figure 5: Distributions of the passenger car damage

3.2.4 Locations of the collision points on the cars

The distributions of the passenger car damage cases from F5 and F6 are shown in Figure 5.

As can be seen, the front structure of the passenger car is the most frequently damaged part. 94.0% of all the damage cases in F5 and 93.3% in F6 happened here.

Using the hypothesis presented in 2.2.3, the distributions of the collision point locations were estimated. According to the detective area of the sensor system, the damage cases which happened on the parts other than the car front were ignored. As a result, the distributions of collision point locations were obtained, as shown in Table 9.

Accident Scenario	Left-Front	Middle-Front	Right-Front
F5	24.5%	51.0%	24.5%
F6	22.2%	49.4%	28.4%

Table 9: Distributions of the collision point locations

3.3 Mathematical model for the sensor evaluation

Based on the developed qualitative and quantitative knowledge of the accident scenario F5 and F6, the mathematical model, as shown in Figure 6, was developed to evaluate the sensor effectiveness.

For any case covered by this model, D_c can be calculated by

$$D_c = V_c \times T_r \tag{2}$$

Where V_c is the car velocity and T_r is the latency of the sensor and protection system. D_p can be calculated by

$$D_p = V_p \times T_r \tag{3}$$

Where V_p is the pedestrian speed. D_s and Y_p can then be obtained by

$$D_s = V_c \times \tan(\alpha) \tag{4}$$

$$Y_p = V_p - Y_c \tag{5}$$

If Y_p is smaller than D_s, the sensor system can detect the pedestrian on time.

If the sensor effectiveness in the whole accident scenario F5 or F6 needs to be evaluated, the density functions of the car velocities and pedestrian speeds can be used in Equation (2) and (3) as V_c and V_p. Y_c is also a random variable. According to Equation (4) and (5), Y_p and D_s are the functions of these random variables. The sensor effectiveness for pedestrian detection can therefore be calculated by

$$P = 1 - \int_0^{\infty} Y_p(x) \int_0^{x} D_s(y)\, dy\, dx \tag{6}$$

Where P is the probability of the pedestrian being detected on time by the sensor system, $Y_p(x)$ and $D_s(y)$ are the density functions of Y_p and D_s.

3.4 Evaluation of the sensor system

According to the analysis of the collision point locations in 3.2.4, the body collision points were concentrated on the left, middle and right front points of the passenger cars. If the width of the passenger cars was set as 1.8m, the distributions of Y_c were obtained as shown in Table 10.

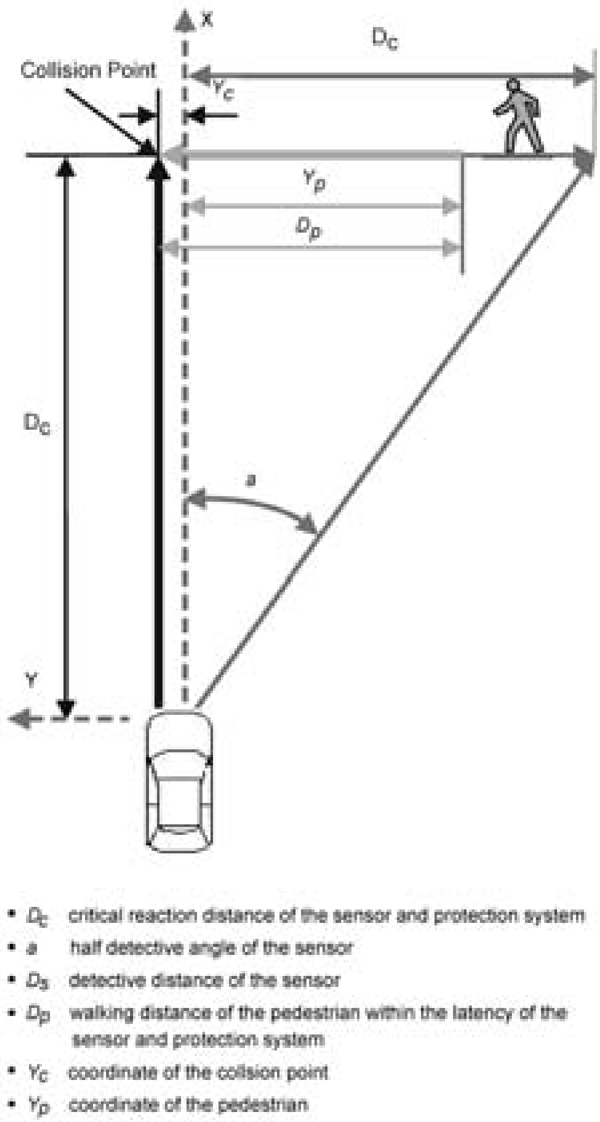


Figure 6: Mathematical model for the sensor evaluation

Accident Scenario	Y_c		
	-0.6m	0m	0.6m
F5	24.5%	51.0%	24.5%
F6	28.4%	49.4%	22.2%

Table 10: Distributions of the Y-coordinates of the collision points

All the pedestrians in F5 and F6 were considered coming from the right side of the cars. If it was assumed that T_r was 510ms, for each Y_c value listed in Table 10, the normal distributions of Y_p, as indicated in Table 11, were calculated by Equation (3) and (5).

Y_c (m)	Accident Scenario	Yp					
		Mean (m)			Standard Deviation (m)		
		Pedestrian Walking	Pedestrian Running		Pedestrian Walking	Pedestrian Running	
			5–39	40+		5–39	40+
-0.6	F5	1.36	2.49	1.93	0.15	0.39	0.21
	F6	1.38	2.54	1.93	0.16	0.40	0.22
0	F5	0.76	1.89	1.33	0.15	0.39	0.21
	F6	0.78	1.94	1.33	0.16	0.40	0.22
0.6	F5	0.16	1.29	0.73	0.15	0.39	0.21
	F6	0.18	1.34	0.73	0.16	0.40	0.22

Table 11: Normal distributions of Y_p

Alpha (degrees)	Accident Scenario	D_s	
		Mean (m)	Standard Deviation (m)
45	F5	7.42	1.20
	F6	7.43	1.22
30	F5	4.29	0.69
	F6	4.29	0.70
15	F5	1.99	0.32
	F6	1.99	0.33

Table 12: Normal distributions of D_s

Alpha (degrees)	Accident Scenario	P	
		Pedestrian Walking	Pedestrian Running
45	F5	1.000	1.000
	F6	1.000	1.000
30	F5	1.000	0.998
	F6	1.000	0.997
15	F5	0.991	0.734
	F6	0.987	0.657

Table 13: Possibility of the pedestrians being detected on time

If alpha was chosen as 45, 30 and 15 degrees, the normal distributions of D_s, as indicated in Table 12, were calculated by Equation (2) and (4).

Using Equation (6) and the conditional probability theory, the P values shown in Table 13 were calculated.

4 Discussions

In the classification of the STRADA accident scenarios, the pedestrian trajectory, the car trajectory and the accident location are the basic traffic elements which are used to differentiate the accident scenarios. In the three traffic elements, the accident location – roadway or intersection – is the primary factor which is used to distinguish the different accident scenarios. The pedestrian trajectory is the secondary most important factor while the passenger car trajectory is comparatively less important in the classification. This classification has a certain drawback. The major problem is that some accidents in which the cars have obviously different moving trajectories are classified into the same accident scenario. For example, the accidents in which the passenger car turns are categorized into the accident scenario F3 with the accidents in which the passenger car goes straight ahead. This problem makes the discrimination of the car trajectories in the accident scenario F3 and F4 impossible.

As can be seen from Table 13, the P values in this study were calculated respectively for walking and running pedestrians. In fact, the actual P values are smaller than the calculated results for walking pedestrians and larger than the results for running pedestrians.

Although not recorded in the STRADA database, in many passenger car-pedestrian accidents, the drivers braked the cars before the collisions. In such cases, D_c should be calculated in consideration of the car deceleration. As a result, in comparison with the same conditions but where the driver did not brake, D_c will be shorter and D_s will be smaller. This will raise the requirement of a larger sensor detection angle. In the mathematical model developed in this study, this situation is not considered. Therefore, the effectiveness of the sensor system can be overestimated.

If the pedestrian visibility is obstructed, the effectiveness of the sensor system can still be calculated by the mathematical model. However, in this case, the sensor system will fail to detect the pedestrian on time not only when Y_p is larger than D_s but also when Y_p is larger than the Y-coordinate of the obstruction object. Because the pedestrian visibility is not recorded in STRADA, this situation is not considered in this study and the effectiveness of the sensor system can therefore be overrated.

5 Conclusions

Among the nine car-pedestrian impact scenarios in STRADA, F5 is the second most common one. If the half sensor detective angle Alpha is equal to or larger than 30 degrees, almost all the pedestrians in this scenario can be detected on time. If the alpha angle is 15 degrees, 99.1% of the walking pedestrians and 73.4% of the running pedestrians can be detected. F6 is the most common scenario. When the alpha angle is equal to or larger than 30 degrees, all the pedestrians in this scenario can be detected on time. But if the angle is 15 degrees, only 98.7% of the walking pedestrians and 65.7% of the running pedestrians will be detected. In order to detect all the pedestrians in the scenario F5 and F6 on time, the detective angle of the sensor system (twice the alpha angle) must be kept larger than 60 degrees.

Acknowledgment

This study is sponsored by the Intelligent Vehicle Safety Systems (IVSS) Programme, Sweden.

References

1. L.J. SCHOFER, K.K. CHRISTOFFEL, M. DONOVAN, V.J. LAVIGNE, R.R. TANZ, E.K. WILLS (1995): Child Pedestrian Injury Taxonomy Based on Visibility and Action, Accident Analysis and Prevention, Vol. 27, No. 3, pp. 317-333
2. C.J .STUTTS, W.W. HUNTER, E.W. PEIN (1996): Pedestrian-Vehicle Crash Types: An Update, Transportation Research Record, Issue 1538, pp. 69-74
3. Swedish Road Administration (2005): Swedish Traffic Accident Data Acquisition, Sweden
4. J. EUBANKS, F.P. HILL, A.D. CASTEE I(2004): Pedestrian Accident Reconstruction and Litigation, 2nd ed, Lawyers & Judges Publishing Company, Tucson, Arizona, U.S.A.
5. A.C. SVEDUNG (2005): Speeds and Time Gaps, Swedish Road Administration, http://www.vv.se/, Sweden

C. Haasper, D. Otte, K. Knobloch, C. Probst,
C. Krettek, M. Richter
Trauma Department/Accident Research Unit,
Hannover Medical School (MHH), Hannover,
Germany

A Medical and Technical Analysis of Knee Injuries Focusing Vulnerable Road Users and Restrained Car Drivers in Road Traffic

Abstract

Description of road traffic related knee injuries in published investigations is very heterogeneous. The purpose of this study was to estimate the risk of knee injuries in real world car impacts in Germany focusing vulnerable road users (pedestrians, bicyclists and motorcyclists) and restrained car drivers.

The accident research unit analyses technical and medical data collected shortly after the accident at scene. Two different periods (years 1985-1993 and 1995-2003) were compared focusing on knee injuries (Abbreviated Injury Scale (AIS_{Knee}) 2/3). In order to determine the influences type of collision, direction and speed as well as the injury pattern and different injury scores (AIS, MAIS, ISS) were examined.

1.794 pedestrians, 742 motorcyclists, 2.728 bicyclists and 1.116 car drivers were extracted. 2% had serious ligamentous or bony injuries in relation to all injured. The risk of injury is higher for two-wheelers than for pedestrians, but knee injury severity is higher for the latter group. Overall the current knee injury risk is low and significant reduced comparing both time periods (27%, p<0,0001). Severe injuries (AIS_{Knee} 2/3) were below 1%). Improved aerodynamic design of car fronts reduced the risk for severe knee injuries significantly (p=0,0015). Highest risk of injury is for motorcycle followed by pedestrians, respectively. Knee protectors could prevent injuries by reducing local forces. The classically described dashboard injury was rarely identified.

The overall injury risk for knee injuries in road traffic is lower than estimated and reduced comparing both periods. The aerodynamic shape of current cars compared to older types reduced the incidence and severity of knee injuries. Further modification and optimization of the interior and exterior design could be a proper measurement. Classic described injury mechanisms were rarely identified. It seems that the AIS is still underestimating extremity injuries and their long term results.

Introduction

Description of road traffic related knee injuries is very heterogeneous. The purpose of this study was to estimate the risk of knee injuries in real world car impacts in Germany focusing vulnerable road users (pedestrians, bicyclists and motorcyclists) and restrained car drivers. With the increasing use of safety belts and availability of air bags, more occupants survive serious car crashes [14]. However, many people involved in frontal or offset crashes incur disabling lower extremity injuries [23, 22, 21]. Though lower extremity injuries are usually not life threatening, the physical and psychosocial consequences of lower extremity injuries are often long lasting. Next to the high risks subsequently high costs follow lower limb injuries [27, 18, 12]. The knee is the largest and one of the most complicated joint of the human body. Eight joint parts cooperate here and allow a limited rotation around its longitudinal axis besides extension and flexion of the lower extremity. Two cruciate and two collateral ligaments stabilize the knee passively. The menisci counterbalance the different bone surfaces. In case of an injury of the knee, one or more of these ligamental or bony elements can be injured and the probability of long-term problems is high due to the complexity [9]. In case of an crash event with a knee injury there is a high likelihood of residual long-term effects [8].

YANG [26] reported in a study using a mathematical simulation of knee movements different injury patterns of the leg. Fractures of the tibia and/or knee injuries such as ruptures of the ligaments and fractures of the condyles were frequently found in experimental studies; he mentions studies by BUNKETORP, ALDMAN, KRAMER, PRITZ and CAVALLERO [2, 10, 11, 16, 20]. Also accident analyses report knee injuries by APPEL, ASHTON and MAKI [3, 17, 4]. A study carried out in Dublin found in a post mortem investigation at the Department of Forensic Medicine, knee joint injuries in 214 out of 357 fatal pedestrian victims of traffic accidents (60%) [25]. Although there are previous studies trying to outline distinct characteristics there is a lack of in-depth technical evaluation for preventive interventions. Most of the previous study analyzed medical, police, and/or insurance records [6, 7, 15, 5]. Under consideration of the results of previous studies with other priorities, we strongly believe that a technical in-depth crash investigation in combination with a medical data analysis is the most sufficient basis for an improvement of safety lower limb injury risk.

The purpose of this study was to analyze the incidence of road traffic knee injuries in Germany by demographic data, place and person co-ordinates and to identify clusters.

Methods

The accident research unit analyses technical and medical data collected shortly after the accident at scene. Two different periods (years 1985-1993 and 1995-2003) were compared focusing on knee injuries (Abbreviated Injury Scale (AIS_{Knee}) 2/3). In order to determine the influences type of collision, direction and speed as well as the injury pattern and different injury scores (AIS, MAIS, ISS) were examined. The vulnerable road users were distinguished as pedestrians, motorcyclists and bicyclists.

n=16563 accidents with 22804 injured persons were identified (Table 1). A total of, 11111 accidents of all traffic participants for the years 1985 to 1994 and 11693 accidents for the years 1995 to 2003 (current situation) were available. From these cohorts the injury frequency of the knee for different types of traffic participation (occupants of cars and trucks, vulnerable road users) including the slight soft tissue injuries were determined in this study.

For vulnerable road users two different groups of accident data were compared, in which a car hits a vulnerable road user: the years 1985 to 1993 (n=2739 persons), and 1995 to 2003 (n=2749 persons). The vulnerable road users were differentiated as pedestrians (n=1794), motorcyclists (n=742) and bicyclists (n=2728). Only those accidents were selected that involved cars (vans included). For the same periods restrained car drivers were selected (n=591 vs. n=525). The accidents with injuries to the knee were compared to all accidents of traffic participants.

Accident reports collected between 1985 and 2003 were carefully analyzed for knee injured road traffic participants and the following parameters: demographic data, AIS, MAIS, ISS, incidence of polytrauma, incidence of serious or severe injuries, role of traffic participation, collision speed, collision opponent, and collision type. For statistical analysis of the correlation between crash circumstances with injury severity (AIS, MAIS, ISS) a t-, Pearson- or Linear-Trend-test was used. The classification of the injury severity was executed according to AIS (American Association for Automotive Medicine 1998 [1]). The documentation was conducted using the same methodology for the whole period of data collection, which allowed for a statistical comparison of the accident structure between early cases and today. These cases were checked by an experienced surgeon based on the AIS-classification and the medical evaluation of the injury pattern and injury patterns of the knee were defined. Knee injuries examined in this study were defined from the distal femur epiphysis including condyles to the tibial head with epiphysis, as well as all ligaments including bone insertion, menisci and the patella and the soft tissue surrounding these structures. The AIS classification considers contusions and smaller soft tissue lesions as AIS 1, soft tissue injuries of a greater extent (sprains) with injuries of bursa, ligaments or menisci, patella fractures, non-compound and only slightly shifted fractures of the tibia, knee dislocations and an open joint are allocated AIS degree 2 whereas fractures of the distal femur, compound or comminute proximal tibia fractures, full posterior cruciate ligament ruptures and open ligament ruptures are classified as the highest degree of injury severity AIS 3 (Table 2). Different technical parameters were focused and examined like influence of car shape developments on injury, the severity outcome of the knee injury pattern in vulnerable road users and finding the characteristics and mechanisms of knee joint injuries. An evaluation concerning the occurring mechanics that were operative during the impact and subsequently applied to the knee unit was conducted. For this purpose, the position of the pedestrian or the cyclists that was derivable from the reconstruction of the accident was taken into account and the resulting kinematics were determined from the damage to the vehicle and the evaluated throwing motion and differentiated according to the occurring load characteristics as direct impact, bending, rotation and combinations of these. A comprehensive reconstruction of the

	total	kind of traffic participation				
		car occupant	truck occupant	motorcyclist	bicyclist	pedestrian
Year of accident 1985-1993						
Total (n)	11111	5891	401	1052	2304	1463
Head	47.7%	48.1%	51.3%	23.2%	52.3%	55.8%
Neck	19.9%	33.1%	22.2%	7.8%	4.9%	4.1%
Thorax	29.8%	37.6%	24.6%	22.5%	20.9%	22.0%
Upper extr.	37.1%	28.0%	36.9%	49.2%	47.6%	44.4%
Abdomen	8.2%	9.0%	8.1%	7.7%	6.3%	8.8%
Pelvis	10.7%	7.8%	7.4%	16.0%	12.2%	16.3%
Femur	9.2%	4.8%	7.8%	16.9%	12.1%	15.5%
Knee	23.5%	14.4%	22.0%	42.2%	31.5%	30.9%
Lower leg	16.0%	9.0%	13.0%	29.0%	20.9%	25.7%
Foot	13.2%	7.1%	7.9%	29.6%	17.2%	18.2%
Year of accident 1995-2003						
Total (n)	11693	6824	507	1227	2018	1117
Head	36.6%	35.1%	45.0%	17.0%	42.1%	52.8%
Neck	30.2%	46.7%	38.1%	7.5%	5.6%	4.9%
Thorax	27.6%	31.2%	32.9%	26.3%	20.5%	19.9%
Upper extr.	31.3%	22.4%	42.8%	45.0%	44.3%	37.4%
Abdomen	6.8%	6.7%	15.5%	6.9%	5.1%	7.4%
Pelvis	8.2%	5.0%	12.1%	14.6%	10.7%	13.4%
Femur	4.7%	2.5%	5.1%	9.4%	6.6%	8.7%
Knee	17.2%	10.0%	16.6%	36.1%	25.4%	21.8%
Lower leg	9.6%	5.0%	10.6%	17.6%	14.6%	17.6%
Foot	7.7%	3.3%	4.9%	17.6%	12.7%	14.1%

Table 1: Distribution of injuries in selected road traffic users

AIS Knee	
1	Contusion
2	Soft tissue injuries incl. ligaments, menisci; patella fractures; closed, minimal displaced tibial fractures; knee dislocation; opened joint cavity
3	Fractures of the distal femur; open, displaced or multifragmentary tibial fractures

Table 2: AIS Knee (based on AIS 1998)

vehicle motion sequence and the accident severity that occurred can be determined on the basis of scaled drawings and a technical impact analysis. Accident characteristics, such as delta-v, EES or deformation depth can be correlated to the classified injury severities. The injuries were documented using independent documentation and the inspection of medical diagnosis reports and x-rays. The documentation contains graphical material and drawings of the accident traces at the site of the accident, detailed measurements of the damages to the vehicle are taken and an accident reconstruction of the motion sequence using computer aided simulation (PCcrash) is conducted. From these data the origin, the type and the extent of the injuries can be determined. The analysis of the accident mechanism and the accident load from the technical point of view is conducted in parallel, based on the analysis of technical data photographs.

Results

1.794 pedestrians, 742 motorcyclists, 2.728 bicyclists and 1.116 car drivers were extracted (Table 1).

Car occupants

After grouping in the years 1985-1993 and 1995-2003 all cases of knee injuries with a severity of AIS 2+ were separated (85-93 n=56; 95-03 n=26). The injuries during the impact and afterwards to the knee were evaluated. End position of the knees of the seated occupants that had been derived from the accident reconstruction was taken into account and the occurring kinematics were evaluated according to the resulting damages in the interior as well as the impact vector and the resulting relative

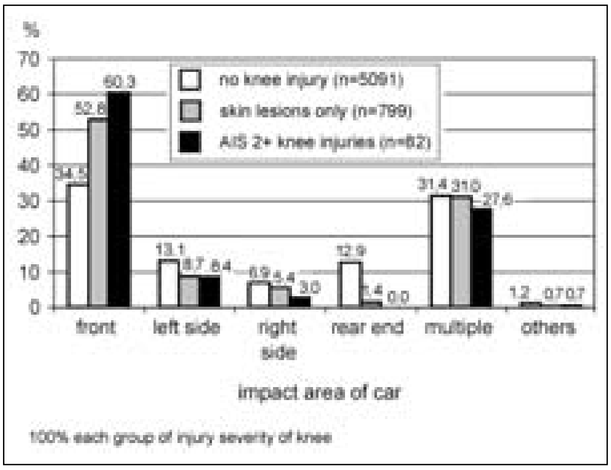


Figure 1: Impact area of restrained car drivers; n=5972 belted injured car drivers

motion of the car (Figure 1) and differentiated according to frontal and side impact it could be demonstrated that an increasing delta-v the incidence of a knee injury and the degree of severity increases.

Up to delta-v values of 50km/h the portion of knee injuries AIS 2+ could be seen in less than 6%. In frontal collisions with a delta-v of up to 20km/h only 0.6% of the drivers suffered from knee injuries AIS 2+ and 13.3% AIS 1, for delta-v from 41 to 50km/h 3.5% AIS 2+ and 25.2% AIS 1 occurred. For side impacts knee injuries of the degree of severity AIS 2+ occurred only in cases of a high accident severity with more than 40km/h delta-v, for a delta-v 41 to 50km/h they registered at 3.0%. 80% of the delta-v values of restrained drivers with knee injures AIS 2+ could be found above delta-v 30 m/h, whereas for drivers without knee injuries 80% of all collisions occurred at delta-v values of up to 40km/h. Whereas 5.1% of the passenger car drivers suffered slight knee injuries AIS 1 and 3.2% of those not injured at the knee had an overall MAIS 3+ injury severity, 54.7% of the drivers who were injured AIS 2+ at the knee suffered from injuries of a degree of severity MAIS 3 or higher. It was remarkable that persons suffering from severe knee injuries as opposed to persons with a slight knee impact trauma AIS 1 and the collective of those occupants of cars in accidents who were not injured at the knee, the proportion of so-called whiplash injuries of the neck occurred significantly less frequently (33.4%, 46.2% compared to 12.8%), whereas all other body regions were more severely injured with increasing severity of the knee injuries. The pelvis was injured four times as frequently in persons with AIS 2+ knee injuries than for passengers/drivers without knee injuries, arm and head and abdomen are injured double frequently. Three quarters of all AIS 2+ knee injured restrained car drivers suffered a fractures of the patella (32.5%) and of the head of the tibia (22.1%) as well as tendon ruptures (24.2%). Fractures of the femur condyles were found in 9.3% of the cases. Where ligament injuries were observed, the medial collateral ligament (11.2%) was affected more frequently than the lateral collateral ligament (2.2%) and the anterior cruciate ligament (10.1%) more frequently than the posterior cruciate ligament. Lateral und medial menisci were injured only in 0.8% of the cases. Severe knee injuries were connected to an intrusion into the passenger compartment. In frontal impacts of cars 43% of the vehicles of restrained drivers with AIS 2+ knee injuries showed an intrusion of the compartment and 32.7% in lateral collisions, in contrast to only 14% of those with light AIS 1 soft tissue lesions of the knee and to only 7.4% of those who were not injured at the leg (16.3% or 12% for a lateral deformation). Intrusion seems to play an important role in the occurrence of severe injuries to the knee. 70% of the cars of the persons with knee injuries AIS 2+ suffered an intrusion at delta-v above 40km/h comparing to those without intrusion where nearly 2/3 delta-v values can be seen up to 40km/h. OF car occupants having severe knee injuries AIS 2+ only 54.7% did not suffer from accompanying injuries of the lower leg, foot, thigh and pelvis. 22.8% suffered from a fracture of the thigh, 13% of the pelvis, 18.8% of the lower leg, 9.6% of the foot and ankle and 0.9% of the hip. Patella fractures are accompanied in 27.1% of the cases by femur fractures und in 18.2% by fractures of the lower leg. The area of the foot is still relatively frequently injured at 11.7%. Ligament injuries frequently also involve injuries of the lower leg or foot. Collateral ligament lesions (medial as well as lateral) were linked with pelvis injuries (30%/50%). This characterizes the extreme torsion of the foot and lower leg resulting in tensile loads in the ligament structures of the knee. Thus severe knee injuries were correlated to intrusions of the passenger compartment in 32.7% of the cases. Patella fractures, fractures of the femur condylus and tendon ruptures could be observed starting at delta-v 20km/h. While restrained car drivers without any knee injury had a mean delta-v value of 29.4km/h and those with knee soft tissue lesions AIS 1 had 37.8km/h, all kinds of knee injuries AIS 2+ occurred with higher accident severity of mean delta-v of

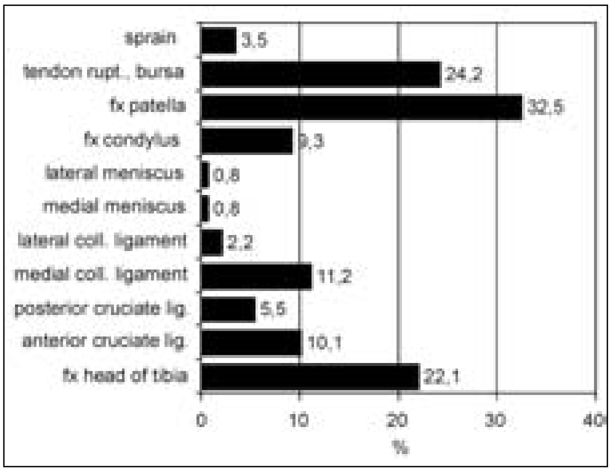


Figure 2: Knee injuries of restrained car drivers

46.1km/h (tibia plateau fracture) until mean delta-v of 60.3km/h for medial collateral ligament lesions. Remarkable seems the fact that ligament injuries of the cruciate and collateral structure of the knee higher load was responsible than for the bony fractures of the head of tibia, condylus and patella (Figure 2). A comparison of airbag and non airbag cases demonstrated a higher risk for knee injuries with airbag deployment. Especially for higher delta-v >30km/h a significant higher portion of AIS 1 knee injuries can be established by 25% for delta-v 31-40km/h and 142% for delta-v 41-50km/h.

Vulnerable road users

Highest frequency of knee joint injuries can be established for motorized two-wheelers, i.e. 42% of motorcyclists suffered knee injuries in accidents 1985-1993 compared to 36% in 1995-2003. The lowest frequency was in pedestrians, where 22% were injured at the knee in the course of accidents in 1995-2003. In case of a serious injury (AIS 2/3) for pedestrians, fractures of tibia head can often be observed (50.8%), for motorcyclists, tendon ruptures and ruptures of frontal cruciate ligament are very frequent (36.7%/20.9%).

If the investigation would be limited to bony and ligamentous injuries of the knee area, such injuries occur in less than 3%. They occur currently (1995 to 2003) at 1.2% of the pedestrians (formerly 2.6%), at 0.5% of the bicyclists (formerly 0.8%) and 1.6% of the motorized two-wheelers (formerly 1.9%).

70% of all measured impact velocities rated between 20 and 60km/h of the car, for pedestrians as well as bicyclists, whereas for patients without knee injury they rated 10 to 50km/h. For motorcyclists 70% of the determined relative velocities were found to be between 20 and 75km/h, these occurred for motorcyclists with knee injuries at 30 to 90km/h. Thus the impact speed is a dominant predictor for knee injury risk and is following in more injury severity of the whole human body. The resulting severity of the injuries of patients with knee injuries was significantly higher. Only 45.6% of the persons with knee injuries were assigned with a rate for minor injury MAIS 1 and 25.4% had a MAIS 3+ (without knee injuries 9.7%).

In case of a severe knee injury motorcyclists suffer more frequently than other road users ruptured tendons of the bursa (36.7%) and the anterior cruciate ligaments (20.9%), whereas pedestrians frequently suffer from tibia plateau fractures (50.8%) and medial ligamental lesions (20.7%). Injured bicyclists frequently show fractures of the patella (17%) and of the tibial plateau (27.2%). Injuries of the condylus, of the meniscus and the lateral ligaments were detected relatively rarely, especially for bicyclists.

Pedestrian impacts

A high risk for knee injuries arises obviously in the case of an impact of a car to the right side of a body because this situation leads to high loads to the knee elements (Figure 3). Where 32.6% of all pedestrians with no knee injuries had an impact from the right, 45% of all pedestrians who suffered from injuries to ligaments and bones of the knee were hit from the right. Such an overrepresentation was not apparent for the other sides of impact. It was differentiated if the struck sided knee was injured or the opposite one. For this analysis all laterally collided pedestrians and bicyclists with knee injuries were put together and found that sprains (86.2%), outer meniscus lesions (100%), fractures of condylus (73.7%) and of tibia head (74.8%) mostly linked with the struck side. In contrast, fractures of patella (34.4%) and medial meniscus lesions (48.6%) and tendon ruptures (40.5%) were often injured on non-struck side of the legs. It can be seen in the diagram that the highest frequent injury location for the non-struck sided knee can be registered for inner ligament lesions (31%) and for the struck side fractures of head of tibia can be seen in 40.4%.

Bicycle impacts

60.9% of all collisions between cars and bicycles resulting in an osseous/ligamentary knee injury

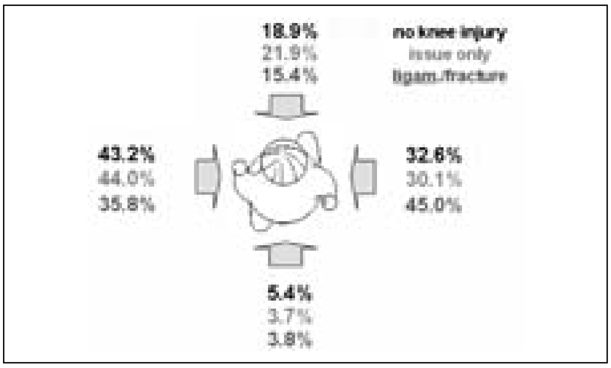


Figure 3: Impact directions of pedestrians comparing persons with and without knee injuries

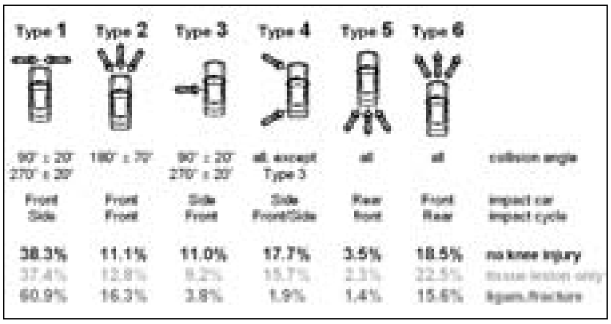


Figure 4: Collision configurations of bicycle to car impacts comparing victims with and without knee injuries

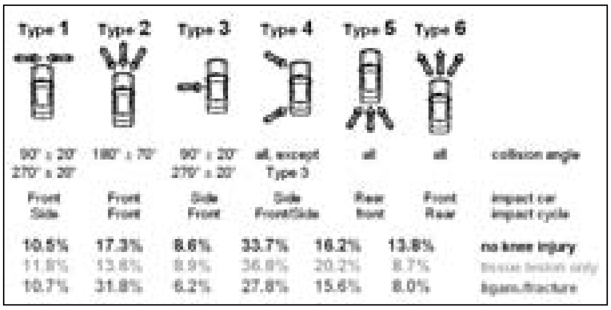


Figure 5: Collision configurations of motorcycle accidents compared victims with and without knee injuries

occur at near right angles, where the front end of the vehicle hits the side of the bicycle (Figure 4). In contrast, this type collision configuration occurs only at 38.7% of all bicyclist accidents without knee injury and in 37.4% of bicyclists with tissue lesions only.

Motorcycle impacts

For motorcyclists the angled to frontal impact of the motorcycle to the front of the car seems to be especially dangerous where osseous/ligamentous knee injuries (31.8% of all persons with knee injuries in comparison to 17.3% without knee injury) were observed (Figure 5). In contrast, the exactly perpendicular impact of a car front against the side of the motorcycle does not seem to increase the risk for knee injuries. This type of head on collisions constitutes 8.9% of all collision situations of the motorcycle driver against a car, this type of collision was also present for those 6.2% that suffered only bony of ligamentous injuries of the knee. It was apparent that for bicyclists and pedestrians the simple distortions and injuries of the outer meniscus and the outer ligaments occur at rather lower velocities, whereas motorcyclists suffer them at rather higher speeds. Injuries of the medial ligaments and tibia plateau fractures for the latter occur at lower impact speeds, however. Tendon ruptures and bursa injuries seem significantly related to higher velocities.

Mechanisms vulnerable road users

A direct impact force was responsible in 31.2%, in 9.6% bending and in 5% rotation can be seen as mechanisms (Figure 6). In 41.7% a combination of direct force plus bending could be established in

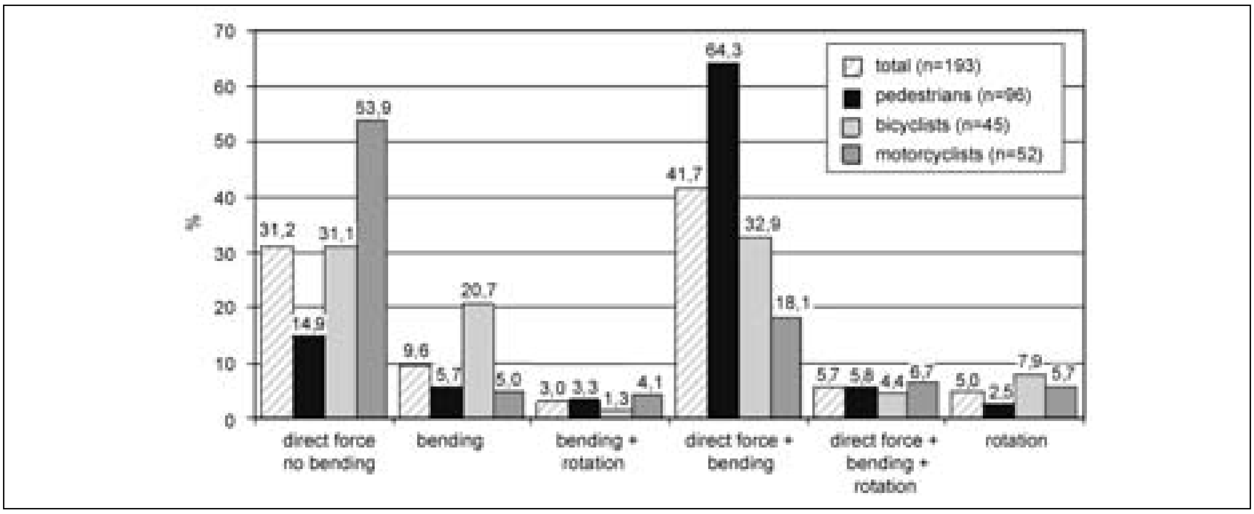


Figure 6: Mechanisms of knee injuries in vulnerable road users

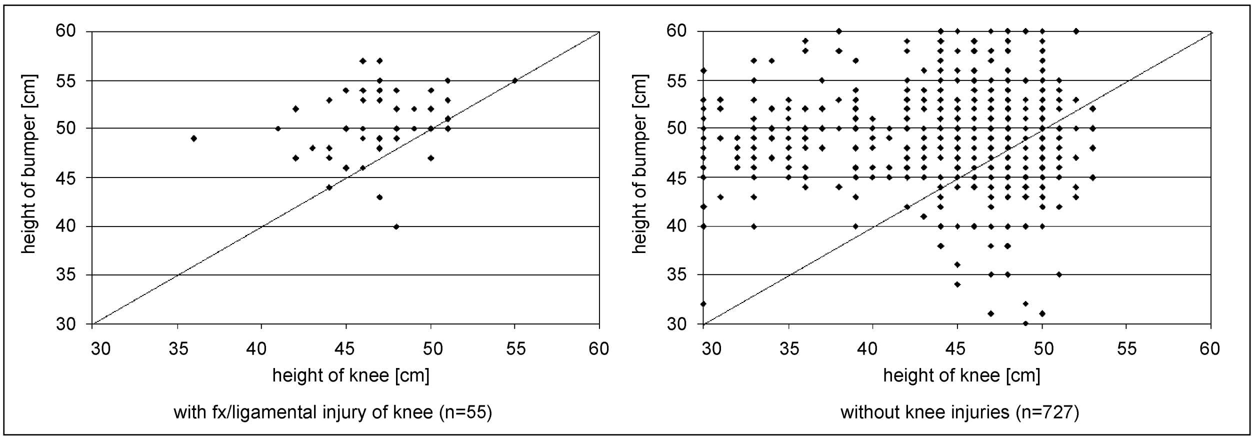


Figure 7: Bumper height and knee height for pedestrian accidents comparing persons with and without knee injuries

many cases. A difference in the collisions of the individual types of traffic participants was noted. Pedestrians frequently suffered at 64.3% from direct force and bending, whereas motorcyclists at 53.9% frequently suffered from direct force without bending. Knee injuries based on isolated rotation was in contrast detected relatively infrequently. In most of the cases rotation occurred together with bending.

It is remarkable that a lateral impact results very often in a tibia plateau fracture. This can be seen especially in car to pedestrian accidents but also in car to bicycle collisions and can be opposed to many studies, claiming that a valgus stress and an increase in force to the medial collateral ligament, which in turn then tears, occur. The analyzed mechanism for the tibia plateau fracture is related mainly to a lateral impact with bending of the ligaments. In the course of the accident, the medial collateral ligament seems to last and the increase in force seems to lead to pressure on the lateral compartment, i.e. the femur condylus is pressed on the tibial plateau while the medial collateral ligament resists, resulting in a tibia plateau fracture. Therefore 16.2% of the lateral collided cyclists with knee injuries suffered a tibia plateau fracture and 40.4% of the pedestrians suffered this kind of injury on the struck sided leg. This can be confirmed by the resulting severity of the tibia plateau fracture according to Schatzker 1 to 3 that represents two third of all kind of tibia plateau fractures.

The height of the bumper seems to have some sort of influence on the development of osseous and/or ligamentary knee injuries (Figure 7). If the bumper induces energy in the area of the knee or above it, knee injuries are extremely significant. Only few cases were found where a knee injury has occurred and the bumper was situated below the knee. 2% had serious ligamentous or bony injuries in relation to all injured. Improved aerodynamic design of car fronts reduced the risk for severe knee injuries significantly (p=0,0015).

The risk of injury is higher for two-wheelers than for pedestrians, but knee injury severity is higher for the latter group. Overall the current knee injury risk is low and significant reduced comparing both time periods (27%, $p<0{,}0001$). Severe injuries (AIS_{Knee} 2/3) were below 1%). Highest risk of injury is for motorcycles followed by pedestrians, respectively. The classically described dashboard injury was rarely identified.

Conclusion

The overall injury risk for knee injuries in road traffic is lower than estimated and reduced comparing both periods.

Most of the authors reported on risk of knee injuries for unrestrained situations. Lower limb injuries occurred to front seat occupants in more than one in three head-on crashes involving casualties. A classically mechanism described by SANDERS [24] is known as the “dashboard injury”. Axial load after contact with the instrument panel results in complex knee-femur-hip injuries. Those are patella fractures, posterior cruciate ligament ruptures, femur fractures and acetabulum fractures. It is an indicator for the degree of severity of the patients injury [19]. However although our investigation was reversed from knee injuries to correlating injuries of the femu-hip-pelvis complex we were unable to identify this injury often.

DISCHINGER [13] noticed in a US study for accidents occurring in the years 1991 to 1994 that men suffered more frequently from factures of the pelvis and women from factures of the lower extremities. Patella fractures occurred in 2% of the drivers protected by a seat-belt, more frequently with airbags than without. People suffering from knee injuries cause the second highest costs for medical treatment today. For the emergence of knee injuries the impact situation of the vehicle plays an important role. Still, car occupants do not number among the especially risk exposed traffic participants with knee injuries. These occur especially frequently among the so-called “vulnerable road users”. According to our investigation about 36% of the motorcyclists, 25% of the bicyclists and 22% of the pedestrians suffer knee injuries of the degree of severity AIS 1+, if they are victims of a traffic accident, whereas only 10% of the car occupants are thus concerned. The introduction of the safety belt, a continuously optimized safety features equipment in cars, with padding and ‘defusing’ of the dash board resulted in this significant reduction of the risk of knee injuries in a car.

A study carried out by TERESINSKI [25] found in a post mortem investigation at the Department of Forensic Medicine in Dublin, knee joint injuries in 214 out of 357 fatal pedestrian victims of traffic accidents (60%). He pointed out that knee injuries are frequently observed in pedestrian victims of traffic accidents and in his description of mechanisms he showed that the cross-section of tibial and femoral epiphyses bone bruises due to compression and avulsion and the bone bruises in the central tibial and femoral condyles were observed only in victims hit in an upright position. There should be a strong correlation between the side of impact on the extremities in medium sized pedestrians (from the front, back, lateral and medial side) caused by passenger cars and the mechanism of knee injuries (hyperextension, anterior dislocation of the proximal tibial epiphysis in relation to the femoral condyles, valgus and varus flexion). In the cases of very low impacts (e.g. in very tall victims hit by rapidly breaking wedge-shaped cars) or very high impact (e.g. in very short victims hit by trucks) the “reversed” complexes of injuries were found (lever principle).

The high percentage of lower extremity injuries as seen in collisions with cars demands further analysis of this type of crash scenario. The forces induced by the bumpers result in a high bending moment at the level of the knee and the proximal tibia. An alteration in design of automobile bumpers with increased padding for example or with exterior airbags may reduce the frequency and/or severity of these injuries. This allows the assumption that an optimized height design of the bumper and an optimization of the front end of the car can lead to a reduced risk of injury where a knee impact trauma is concerned.

The study showed that the motorcyclists are under risk for knee injury if a frontal direct impact to the knee occurs and based on the resulting relative motion of the human body on the bike a load is transmitted frontally to the patella following in patella fractures. Based on the following movement of the human off the bike a bending rotation mechanism is possible transmitting stress load to the ligaments on one hand. It is also possible that the tibia is forced posterior relative to the femur. The posterior cruciate ligament is usually tight when the knee is in 90 degree flexion and is therefore at high risk for disruption. The conclusions found in the course of this study can be used to improve the current computer simulation of motions and load behavior. They can also supplement the current component tests for the protection of pedestrians concerning kinematics resulting in knee injuries and finally they can also be used to include the requirements for the bicycle impact into such test regulations

However, the influence of air bags on lower extremity injuries, and in particular injuries to the knee, has not been examined effectively in previous field studies since they lacked sufficient number of air bag equipped vehicles in their real world crash dataset. Not only the knee bag or use of restraint devices in the car must be mentioned furthermore there is a need for developing technical features to protect the vulnerable road user.

Pedestrians’ injuries gained attention in road crossing, whereas a large proportion of passengers who were injured inside the car passengers exists. The latter were injured while improperly seated without seat-belt protection. An estimated higher risk of knee injuries was confirmed while using motorcycles and bicycles. This study aimed at achieving an increased understanding and knowledge about the accident pattern in the traffic environment in Hannover.

This study let to some new facts about road traffic-related knee injuries. There is definitely a need to continue our observations in an in-depth study regarding the mechanisms of accidents leading to these injuries. Strategies have to be developed to provide effective prevention. Medical and economical consequences of knee injuries in road traffic show that there is a need to enhance active and passive safety devices in road vehicles.

It can be stated that only 1.2% of the pedestrians involved in road traffic accidents, 0.5% of the bicyclists and 1.6% of motorized two-wheeler drivers were injured at the knee in the course of a collision with a car. This incidence can be called a low risk. It was also found that the risk for knee injuries was significantly lower than 10 or 20 years ago. Knee injuries are not necessarily but in general significantly related to a high impact velocity of the car, they have been observed for speeds lower than 10km/h on the one hand, but 50% occurred at speeds above 35km/h for pedestrians and above 25km/h already for accidents involving bicycles, for motorcycle accidents 50% of the relative speeds exceeded 50km/h.

Advancement in vehicular designs, with specific attention to air-bags, dashboards, and firewalls, needs to be made to reduce the incidence and magnitude of lower extremity trauma in motor vehicle accidents. Seat-belts remain the most effective restraint in the prevention of lower extremity trauma in the motor vehicle.

The study also reveals how important scientific in-depth investigations are und that the depth of information also supplies details of comprehensive injury documentation. A limitation to this study is that the population risk, taking into account time spent in each injury relevant activity is not available. This is shared by most real-world injury investigations.

The aerodynamic shape of current cars compared to older types reduced the incidence and severity of knee injuries. Further modification and optimization of the interior and exterior design could be a proper measurement. Classic described injury mechanisms were rarely identified. It seems that the AIS is still underestimating extremity injuries and their long term results.

References

[1] AAAM: The Abbreviated Injury Scale- 1990 Revision, Update 1998. Des Plaines, IL (1998)

[2] B. ALDMAN, J. KAJZER, O. BUNKETORP: An Experimental Study of a Modified Compliant Bumper. 10th International Technical Conference ESV, 1035-1040 (1985)

[3] H. APPEL, A. KUEHNEL, G. STUERTZ, H. GLOECKNER: Pedestrian Safety Vehicle – Design Elements – Results of In-Depth Accident Analyses and Simulation. 22nd AAAM Conference, 132-153 (1978)

[4] S.J. ASHTON: The Cause and Nature of Head Injuries Sustained by Pedestrians. International Research Committee on the Biokinetics of Impacts 2nd International Conference, 101-113 (1975)

[5] T. ATKINSON, P. ATKINSON: Knee injuries in motor vehicle collisions: a study of the National Accident Sampling System database for the years 1979-1995. Accid Anal Prev 32, 779-786 (2000)

[6] T. ATKINSON, P. ATKINSON: Knee injuries in motor vehicle collisions: a study of the National Accident Sampling System database for the years 1979-1995. Accid Anal Prev 32, 779-786 (2000)

[7] T. ATKINSON, P. ATKINSON: Lower extremity injuries in motor vehicle collisions: a survey of NASS 1997-1999. International Journal of Vehicle Design 32, 173-183 (2003)

[8] B. BRAUTIGAN, L. JOHNSON: The epidemiology of knee dislocations. Clin Sports Med 19, 387-397 (2000)

[9] B. BRAUTIGAN, L. JOHNSON: The epidemiology of knee dislocations. Clin Sports Med 19, 387-397 (2000)

[10] O. BUNKETORP, B. ALDMAN, R. EPPINGER: Experimental Study of a Compliant Bumper System. Ircobi Stapp Conference 287-297 (1983)

[11] C. CAVALLERO, D. CESARI, M. RAMET: Improvement of Pedestrians Safety, Influence of Shape of Passenger Car Front. SAE 830624, 225-237 (1983)

[12] P.C. DISCHINGER, K.M. READ, J.A. KUFERA, T.J. KERNS, C.A. BURCH, N. JAWED, S.M. HO, A.R. BURGESS: Consequences and costs of lower extremity injuries. Annu. Proc. Assoc. Adv Automot. Med 48, 339-353 (2004)

[13] P.C. DISCHINGER, K.M. READ, J.A. KUFERA, T.J. KERNS, C.A. BURCH, N. JAWED, S.M. HO, A.R. BURGESS: Consequences and costs of lower extremity injuries. Annu. Proc. Assoc. Adv Automot. Med 48, 339-353 (2004)

[14] G.J. DUNCAN, R. MEALS: One hundred years of automobile-induced orthopedic injuries. Orthopedics 18, 165-170 (1995)

[15] I. IAKOVAKIS, N. DESSYPRIS, M. DALAMAGA, E. PETRIDOU: A cluster analysis of road traffic-related childhood knee injuries. Child Care Health and Development 29, 297-301 (2003)

[16] M. KRAMER, K. BUROW, A. HEGER: Fracture Mechanism of Lower Legs Under Impact Load. 17th Stapp Car Crash Conference 81-100 (2005)

[17] T. MAKI, J. KAJZER, K. MIZUNO, Y. SEKINE: Comparative analysis of vehicle-bicyclist and vehicle-pedestrian accidents in Japan. Accid Anal Prev 35, 927-940 (2003)

[18] T.R. MILLER, N.M. PINDUS, J.B. DOUGLASS: Medically Related Motor-Vehicle Injury Costs by Body Region and Severity. J Trauma 34, 270-275 (1993)

[19] R. MOSHEIFF, D. SEGAL, R. WOLLSTEIN, S. SAGIV, M. LIEBERGALL: Midshaft femoral fracture, concomitant ipsilateral hip joint injury, and disruption of the knee extensor mechanism: a unique triad of dashboard injury. Am J Orthop 27, 465-473 (1998)

[20] H.B. PRITZ: Comparison of the Dynamic Responses of Anthropomorphic Test Devices and Human Anatomic Specimens in Experimental Pedestrian Impacts. 22nd Stapp Car Crash Conference, 341-357 (1978)

[21] M. RICHTER, C. BECKER, J. SEIFERT, F. GEBHARD, O. PIESKE, M. HOLCH, G. LOB: Prävention von Verletzungen im Alter. Unfallchirurg 105, 1076-1987 (2002)

[22] M. RICHTER, D. OTTE, H.C. PAPE, S. GLUEER, B. KOENEMANN, H. TSCHERNE: Verletzungen von Kindern und Jugendlichen im Straßenverkehr. Unfallchirurg 104, 733-741 (2001)

[23] M. RICHTER, H. THERMANN, H. RHEINBABEN, E. SCHRATT, D. OTTE, H. ZWIPP, H. TSCHERNE: Frakturen der Fußregion bei Pkw-Insassen. Unfallchirurg 102, 429-433 (1999)

[24] T.G. SANDERS, M.A. MEDYNSKI, J.H. FELLER, K.W. LAWHORN: Bone Contusion Patterns of the Knee at MR-Imaging: Footpoint of the Mechanism of Injury. Scientifc Exhibit RG 20, 135-151 (2000)

[25] G. TERESINSKI, R. MADRO: Knee joint injuries as reconstructive factors in car-to-pedestrian accidents. Forensic Science International 124, 74-82 (2001)

[26] J.K. YANG: Mathematical simulation of knee responses associated with leg fracture in car-pedestrian accidents. IjCrash 2 No 3, 259-271 (1997)

[27] E. ZALOSHNJA, T. MILLER, E. ROMANO, R. SPICER: Crash costs by body part injured, fracture involvement, and threat-to-life severity, United States, 2000. Accid Anal Prev 36, 415-427 (2004)

Session:
Regulations and Consumer Aspects

C. Pastor

F.A. Berg, P. Rücker, M. Gärtner, M. Groer

K. Okamura, K. Mori, Y. Nishida

C. Pastor
Bundesanstalt für Straßenwesen,
Bergisch Gladbach, Germany

Paired-Comparison Study: Correlation between Euro NCAP Star Ratings and Accident Data from the National German Police Road Accident Statistics

Abstract

Today, Euro NCAP is a well established rating system for passive car safety. The significance of the ratings must however be evaluated by comparison with national accident data. For this purpose accidents with involvement of two passenger cars have been taken from the German National Road Accident Register (record years 1998 to 2004) to evaluate the results of the NCAP frontal impact test configuration.

Injury data from both drivers involved in frontal car to car collisions have been sampled and have been compared, using a "Bradley Terry Model" which is well established in the area of paired comparisons. Confounders – like mass ratio of the cars involved, gender of the driver, etc. – have been accounted for in the statistical model.

Applying the Bradley Terry Model to the national accident data the safety ranking from Euro NCAP has been validated (safety level: 1star <2 star <3 star <4 star). Significant safety differences are found between cars of the 1 and 2 star category as compared to cars of the 3 and 4 star category. The impact of the mass ratio was highly significant and most influential. Changing the mass ratio by an amount of 10% will raise the chance for the driver of the heavier car to get better off by about 18%. The impact of driver gender was again highly significant, showing a nearly 2 times lower injury risk for male drivers. With regard to the NCAP rating drivers of a high rated car are more than 2 times more probable (70% chance) to get off less injured in a frontal collision as compared to the driver of a low rated car.

Introduction

Today, Euro NCAP is a well established rating system for passive car safety. The significance of the ratings must however be evaluated by comparison with accident data. The variety of real world crash events raises the question, whether everyday scenarios can be covered by a small number of crash tests, conducted under artificial circumstances. Recent studies have already shown a positive correlation between the NCAP rating and real world crash performance. However, none of the studies have shown the size of the effect as compared to other effects, generated by confounders like mass difference of the cars in a two car crash or gender of the driver, etc. In addition several models have been used which do not account for the multilevel structure of traffic accidents but just compare the relative performance of cars using accident databases.

Hence, the central objective of my study was (1) to detect any correlation between NCAP rating and real world crash behaviour by means of sound statistical models which account for the multilevel structure of accidents as well as (2) to compare the effect attributed to the NCAP rating with other effects attributed to covariates like mass difference of cars or age and gender of the drivers involved.

The Bradley Terry Model

There is considerable existing work in the statistics literature concerning the repeated ranking of members of a group of individuals. The most fundamental model in this field is generally attributed to BRADLEY and TERRY. The Bradley Terry Model deals with the area of paired comparisons, where ranking takes place between members drawn from a group two at a time. In the model each member is assigned a real-valued positive number η. Thus for a group of m individuals, with $\eta=(\eta_1,\dots,\eta_i,\dots\eta_m)^T$, where η_i is associated with individual i, the probability p_{ij} of individual i being superior to individual j is given by

$p_{ij}=\eta_i/(\eta_i+\eta_j)$; $Odds_{ij}=\eta_i/\eta_j$.

The standard model can alternatively be expressed in the logit-linear form

$Logit\,[p_{ij}]=\lambda_i-\lambda_j$, where $\lambda_i=\log(\lambda_i)$ for all i.

Thus, assuming independence of all contests, the parameters λ_i, λ_j, etc. can be estimated by maximum likelihood standard methods.

To put the model in a crashworthiness context, consider the individuals to be passenger cars, being involved in two car collisions. Here η can be thought of as representing the crashworthiness of car i and p_{ij} as the probability of the passengers of car i getting away less injured than the passengers of car j, in a collision between the two. Clearly this model lends itself to the case of one-on-one collisions (1:1 matching or pair matching).

From a statistical point of view the restriction to two-car accidents (1:1 matching) has the advantage that all observed and unobserved characteristics of the accident itself (time, location, weather conditions, severity etc.) are the same for both accident-involved cars and, therefore, these characteristics cannot account for differences in the injury risk of the two drivers involved in the accident. Consequently, the 'pure' effect of NCAP rating on the probability of car driver injury can be measured more precisely. However, on the other hand, a number of accidents (single car accidents, accident between cars with identical rating or accidents with cars not rated) are ruled out and can not be used in the context of this model.

The Bradley Terry Model has been widely studied and has many generalisations and applications in a broad range of areas. In-depth explanations of which can be found in many sources [DAV, HUN, FIR].

When using the Bradley Terry Model in connection with crashworthiness ratings it is fundamental to choose a reasonable "winner function", a function which decides what car is the 'winner' in a car to car competition – or in other words in a two-car accident. There are several possibilities, e.g. defining a Severity Score S

S= f (#fatalities, #serious, #slight)

for each car declaring the car with the lower severity score to be the winner. However, in my study only the injury severity of the driver of each car was used as severity score S, thus the car with the less injured driver won the competition. Having a more sophisticated "winner function" can be beneficial as this can reduce the number of ties, where both parties show the same injury severity score. Clearly those kind of accidents (ties) do not contain any information about the relative crash performance of the two cars involved in the crash.

Data

For purposes of this study a sample of the German police recorded accident register with car to car accidents between 1998 and 2002 was available. These dataset contains NCAP tested vehicles and non-NCPA tested vehicles.

There are 235,047 (out of 981,627) vehicles which could be considered NCAP tested. The classification of car type and model has been done on the basis of the German type- and vehicle-manufacturer code, which distinguishes cars by their motorization, chassis, kind of propulsion, cubic volume to name a few. It was decided that these variables can sufficiently specify a certain car in order to decide whether it is similar to the NCAP tested variant or not.

The sample dataset was supposed to be a 70% sample of the German Official Police Traffic Accident Statistics of car to car collisions where just two cars have been involved in the accident.

Figure 1.1 summarizes the number of accidents with fatal, serious and slight consequences for any car passengers in car to car collisions. The sample dataset contains 53% of all cars where passengers had fatal injuries, 56% of all cars where the driver sustained serious injuries and 57% of all cars with slight injury consequences. If one reduces the sample set to NCAP tested vehicles only, the data contains 9% of all cars with fatal consequences to passengers, 12% of all cars with serious and 14% of all cars with slight injury consequences. Thus it could be estimated that 18% of all fatalities happen in cars which are NCAP tested.

It becomes obvious, that NCAP vehicles are under-represented in the group of fatal and serious

	Fatalities		Serious Inj.		Slight Inj	
	Number	%	Number	%	Number	%
ALL police recorded accident data (1998-2002)	5,327	100	101,265	100	699,700	100
Sample database	2,807	53	56,266	56	401,666	57
Sample database with NCAP tested vehicles only	501	9	11,761	12	97,666	14

Figure 1.1: Sample size of GERDAT and GERDAT_NCAP as compared to the national police data (for accidents involving two cars)

Ctyp	0		1		2		3		4		5		6		7		8	
Atyp	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng
1	1,2	0,2	0,0	0,2	0,2	0,2	0,0	0,2	**17,8**	**9,0**	0,0	0,0	0,0	0,2	3,0	0,4	3,0	1,0
2	0,2	0,0	0,0	0,0	0,0	0,2	0,0	0,0	0,8	0,2	1,2	0,6	0,0	0,0	0,0	0,4	0,0	0,0
3	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,0	0,0	0,0	**15,4**	**3,0**	0,0	0,0	0,0	0,2	0,0	0,0
4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
5	0,0	0,0	0,0	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
6	0,6	0,8	0,2	0,0	0,6	0,6	1,4	1,0	**16,6**	**10,4**	0,0	0,0	0,0	0,2	1,0	0,6	1,2	0,2
7	0,4	0,0	0,4	0,2	0,0	0,0	0,0	0,0	1,8	0,6	0,8	0,0	0,0	0,6	0,6	0,0	0,0	0,2

Figure 1.2: Distribution [%] of combinations of Ctyp (kind of accident) and Atyp (type of accident) for all fatal cases with NCAP tested cars; separated into guilty (g) and not guilty (ng) party (n=501)

Ctyp	0		1		2		3		4		5		6		7		8	
Atyp	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng
1	0,4	0,4	0,3	0,2	0,3	0,4	0,3	0,2	**5,5**	**8,5**	0,1	0,1	0,0	0,0	1,3	0,7	1,3	0,9
2	0,1	0,2	0,1	0,1	0,5	0,9	0,1	0,1	1,6	2,2	3,0	3,9	0,0	0,0	0,0	0,1	0,0	0,0
3	0,1	0,2	0,1	0,1	0,0	0,0	0,0	0,0	0,1	0,2	**13,3**	**14,2**	0,0	0,0	0,0	0,0	0,0	0,0
4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
5	0,1	0,0	0,5	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
6	0,3	1,0	0,4	1,0	2,9	4,5	1,0	1,4	**6,6**	**10,1**	0,1	0,2	0,0	0,0	0,4	0,7	0,4	0,6
7	0,7	0,5	0,5	0,2	0,3	0,1	0,1	0,1	0,6	0,7	0,2	0,2	0,1	0,1	0,2	0,1	0,3	0,1

Figure 1.3: Distribution [%] of combinations of Ctyp (kind of accident) and Atyp (type of accident) for all serious cases with NCAP tested cars; separated into guilty (g) and not guilty (ng) party (n=11,761)

Ctyp	0		1		2		3		4		5		6		7		8	
Atyp	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng	g	ng
1	0,1	0,3	0,2	0,5	0,2	1,1	0,1	0,2	**1,2**	**3,4**	0,1	0,2	0,0	0,0	0,3	0,4	0,3	0,4
2	0,1	0,2	0,1	0,7	0,6	3,2	0,1	0,2	1,2	2,1	3,0	5,6	0,0	0,0	0,0	0,0	0,0	0,0
3	0,1	0,2	0,1	0,2	0,0	0,1	0,0	0,0	0,1	0,2	**9,1**	**18,6**	0,0	0,0	0,0	0,0	0,0	0,0
4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
5	0,0	0,1	0,5	0,7	0,0	0,2	0,0	0,0	0,0	0,1	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0
6	0,2	0,8	0,6	4,4	*3,1*	*21,3*	0,6	1,6	**1,4**	**3,7**	0,1	0,1	0,0	0,0	0,1	0,4	0,1	0,4
7	0,4	0,7	0,3	0,6	0,1	0,6	0,1	0,1	0,2	0,4	0,2	0,4	0,0	0,0	0,1	0,1	0,1	0,1

Figure 1.4: Distribution [%] of combinations of Ctyp (kind of accident) and Atyp (type of accident) for all serious cases with NCAP tested cars; separated into guilty (g) and not guilty (ng) party (n=97,666)

casualties. Although they make up 24% of the sample dataset, they make just 17% of the fatal cases and 21% of the serious cases [fatal: 1/0,53*0,09=0,17; serious: 1/0,56*0,12=0,21].

Looking in more detail at the structure of the accidents described by "kind" and "type" of accident there are some interesting facts becoming obvious (see Figure 1.2 to 1.4).

Certain combinations of the kind of accident (Ctyp), which describes the entire course of events in an accident, and the type of accident (Atyp), describing the conflict situation, turn out to represent most of the fatal casualties. Details on the exact definitions of CTyp and ATyp can be found elsewhere [STA].

The combinations (Atyp/Ctyp), (1/4), (6/4) do represent front to front crashes, (6/4) being the "classical" example for a front to front collision, whereas in (1/4) one party looses control on its car and wherefore receives more often serious consequences. Both types of accidents are responsible for nearly 54% of all fatal casualties in NCAP tested vehicles and nearly 31% of all serious cases in NCAP tested vehicles.

The combination (3/5) mainly builds up of front to side collisions, having the fatal consequences for the guilty party (Figure 1.2). This is usually the vehicle crossing the street and getting the side impact.

Database	Numbers
NCAP vehicles in the SAMPLE DATABASE	235,047
Accidents with at least one NCAP vehicle	212,672
“Front-Front“ accidents with at least one NCAP vehicle	17,962
“Front-Front“ accidents with both cars NCAP-tested	1,963
“Front-Front“ + “NCAP-NCAP“ + accident with at least one person sev. or fatally inj.	495

Figure 2.1: Relevant case numbers in the database

Looking at the slight injury cases (Figure 1.4) the combination (6/2) becomes obvious. These are rear end collisions with a stopping vehicle and the slightly injured person is most often the person in the stopping vehicle.

With regard to the matched pairs design of the study front to front collisions have been considered to produce the most ideal “pair” for two car collisions whereas both cars sustain more or less the same crash severity. This is most truly given in a front to front accident configuration. As described these accidents can be identified by proper combinations of kind and type of accident, here Atyp/Ctyp combinations (1/4) and (6/4). Comparison with the NCAP star rating was thereby restricted to comparisons with the frontal star rating only.

For this study it was furthermore decided that accidents with fatal and serious outcomes should be most meaningful with regard to the NCAP star rating. Here only the injury status of the drivers have been taken into account.

However, the numbers of available accident cases decreases rapidly when the data is restricted to this interesting group of accidents. This is quite natural taking into account the great number of low severity accidents which are excluded from the analysis. Furthermore NCAP tested cars do not often collide with another NCAP tested car, but more often with other not NCAP tested cars, which can be seen by comparing row 1 and 2 of Figure 2.1.

Within the remaining 495 car to car accidents there have been 64 fatalities, 771 severely injured and 453 slightly injured persons.

Data Analysis

The study focuses on frontal car to car collisions of NCAP tested cars and compares the real world performance to the frontal offset test results of the NCAP assessment. The official frontal rating is calculated using the crash dummy readings of both frontal passengers. This rating has been recalculated to assess merely the driver readings, thus giving a frontal rating for assessing the drivers risk of getting injured. This procedure was carried out by the Monash University in the course of the SARAC2 project. Using this kind of assessment complies with the “winner function” as described in the paragraph, describing the Bradley Terry Model.

Before starting the analysis the only 0-STAR car in the database, a Chrysler Voyager, was decided to be taken out. Setting up the data into a winner/loser shown matrix produces the result in Figure 3.1.

Winner	Loser	Frequency	Reduced Frequency
1-STAR	1-STAR	14	-
2-STAR	1-STAR	22	22
3-STAR	1-STAR	28	28
4-STAR	1-STAR	6	6
1-STAR	2-STAR	16	16
2-STAR	2-STAR	48	-
3-STAR	2-STAR	62	62
4-STAR	2-STAR	12	12
1-STAR	3-STAR	12	12
2-STAR	3-STAR	37	37
3-STAR	3-STAR	36	-
4-STAR	3-STAR	10	10
1-STAR	4-STAR	2	2
2-STAR	4-STAR	4	4
3-STAR	4-STAR	9	9
4-STAR	4-STAR	3	-
SUM		321	220

Figure 3.1: Winner-Loser-Frequency Matrix of frontal car to car collisions of NCAP tested cars

Figure 3.1 contains information on 321 car to car frontal collisions. This means that there have been 174 ties out of 495 accidents, where the injury status of both colliding cars have been identical and which have for this reason been of no value for the analysis. However, more cases of the table do not contain valuable information for the model, because winner and loser are of the same category. Referring to the second frequency column in Figure 3.1, the number of valuable accidents reduces to 220. Looking at the matrix the NCAP star rating seems to make sense, since higher rated cars do more often win against lower rated cars and vice versa.

	λ_i Estimate	Std.Error	Signif
1-STAR	0,000	0,000	-
2-STAR	0,306	0,247	0,2145
3-STAR	0,855	0,249	0,0006
4-STAR	1,133	0,378	0,0027
Null deviance: 445 on 321 degrees of freedom Residual deviance: 425 on 318 degrees of freedom AIC: 431			

Figure 3.2: Crashworthiness estimation by using a simple Bradley Terry Model

	λ_i Estimate	Std.Error	Signif
1-STAR	0,000	0,000	-
2-STAR	0,439	0,274	0,1086
3-STAR	0,714	0,274	0,0092
4-STAR	0,900	0,412	0,0291
MR	1,692	0,312	5,9e-08
FEMALE	-0,590	0,191	0,0021
Null deviance: 442 on 319 degrees of freedom Residual deviance: 362 on 314 degrees of freedom AIC: 372			

Figure 3.3: Crash-worthiness estimation by using a Bradley Terry Model with covariates adjustment

Fitting the data to a Bradley Terry Model produces the result, shown in Figure 3.2. Again, there is a clear tendency for better rated cars being more crashworthy than lower rated cars. The standard deviation does not allow for a separation of each class category. Thus it is possible to distinguish between a 1-star and a 3-star car, and also between a 1-star and a 4-star car. All other confidence intervals overlap on a 5% significance level.

By extending the model one can include confounding variables. Mass ratio (MR) defined by

MR=max.weight(winner)/max.weight(loser)

and gender of the driver have shown to be of significance.

Figure 3.3 shows the results. The mass ratio is significantly marked to play an important role in front to front car collisions.

Results

The main results of the study can be summarized as follows:

(1) After adjusting for confounding factors there remains a significant safety difference between cars of the 1- and 2- star category and cars of the 3- and 4- star cars, thus the NCAP star rating seems to be reflected by real world accidents.

(2) The mass ratio of the cars involved in a frontal car to car accident is the most powerful covariate. A 10% change in mass ratio results in a 20% increase in probability to get better off in an accident, or in other words the odds to get better off change from 50/50 to 60/40 for the driver of an equally rated but heavier car.

(3) There is a gender effect. Female drivers show an almost 2 times higher injury risk. The odds change from a 50/50 chance to get better off to a 35/65 chance for a female driver of an equally rated car of similar weight.

(4) The NCAP rating can have at a maximum chance the odds from 50/50 to 30/70, thus the driver of the lower rated car is 2 times more probable to get more injured in a crash.

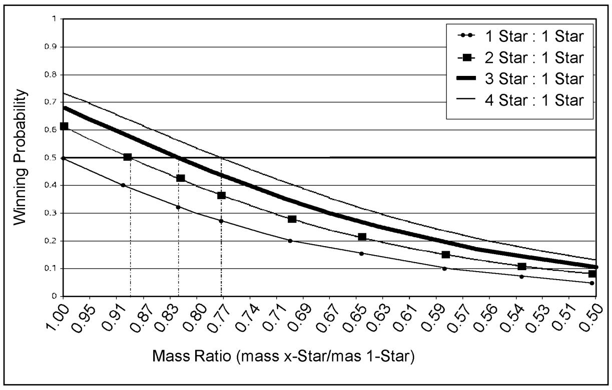


Figure 4.1: Comparison of star rating and mass ratio influence in frontal car to car accidents

The influence of the star rating as compared to the impact of mass ratio is depicted in Figure 4.1. The baseline car for all curves is an impact with a 1-star rated car.

Accidents between two 1 star rated cars with mass ratio 1 show a winning probability of 50% which is trivial. A collision between a 2-star and a 1-star rated car of equal weight shows a winning probability for the 2-star car of 62% and so on. It could be seen that the advantage of a 4-star car as compared to a 1-star car is compensated when the mass ratio reaches a value of 0,77; thus a 2,000kg 1-star car hitting a 1,500kg star 4-star car both will have a 50% probability of getting better off. Similar comparisons could be done with the other covariate which was the gender of the driver. The advantage of driving a 4-star car is thus compensated by the fact of a female driver when hitting a 1-star car with a male driver.

In further analysis it would be desirable to include further covariates like age of driver which has not been considered here. The special dataset of this study did not contain enough information for this purpose. It would furthermore of interest to extend the Bradley Terry Model to make more use of ties (accidents between cars with the same injury severity score).

Acknowledgements

This study was sponsored by the European Commission and carried out in context of the SARAC2 project. The author is especially graceful to the Monash University Accident Research Center (Prof. Max Cameron, Amanda Delaney) for providing data of the recalculated NCAP scores based on the driver dummy readings only.

References

DAV: H.A. DAVID: The Method of Paired Comparisons, 2nd edition, Oxford University Press, New York (1988)

FIR: D. FIRTH: Bradley Terry Models, Journal of Statistical Software, 12, 1-12 (2005)

HUN: D.R. Hunter: MM algorithms for generalized Bradley Terry Models, Annals of Statistics, 32, 384-406 (2004)

STA: Verkehrsunfälle – Fachserie 8, Reihe 7, download via http://www-ec.destatis.de/

F.A. Berg, P. Rücker, M. Gärtner, M. Groer
DEKRA Automobil GmbH, Accident Research & Crash Test Center, Stuttgart, Germany

Crash Tests to Assess the Secondary Safety of Cars in the so-called “8,000-Euro Class”

Abstract

The price of a new car increased almost every year for a long period. In recent years however, the budget available to most people for purchasing a car either did not grow or became even smaller. Therefore it was in the interest of some OEMs to offer economical car models in the so-called “8,000-Euro class”. Here an important question arose regarding the safety of these vehicles. There is no question that the very high safety level of cars reached in Europe during the last decades should not be sacrificed as a consequence of smaller budgets. Customers with sense of responsibility have the right to be properly informed about the balance between safety and price so that they can make a deliberate decision when buying either a new or a used car.

Against this background, the German magazine “AutoBILD” commissioned DEKRA to conduct full-scale frontal crash tests with a view to publishing the results. These tests have been carried out in accordance with the corresponding Euro NCAP crash test requirements and performance criteria. The tested vehicles were two new Logans produced by the manufacturer Dacia, two used cars of the type VW Golf IV (registration date 2000) and one new VW Fox.

This paper describes the safety features of the vehicles and the results of the five crash tests to demonstrate state-of-the-art safety levels and what levels may be expected from vehicles in the “8,000-Euro class”.

Looking at real-world crashes it is of interest to think about future trends in a more detailed manner. Therefore it will be more and more necessary to supplement the federal statistics with more detailed in-depth information about the consequences of accidents and the safety performance of crashed vehicles.

Notation

resp.	respectively
v	velocity [m/s;km/h]
a	acceleration [m/s^2]
M	momentum [Nm]
HIC	Head Injury Criterion [-]

Introduction

According to the “Allgemeiner Deutscher Automobil Club (ADAC)” the expenses for purchase and maintenance of a car in Germany increased by an average of 37.7% from 1991 to 2001, Figure 1. This equals an annual average increase of 3.0%. In contrast, the cost of living expenses have increased by 27.3%, which represents an annual increase of 2.2% over the same period [1]. The main cost factor there has been the increases in fuel prices. In the year 2002 these were 54.9% above the prices in 1991.The purchase price of a car rose in the same period by 18.3% and consequently the increase has been less than that of the increase in the cost of living. However, in the face of a general shortness of money and the high level of retail prices for new cars it is very desirable to save money here.

Against this background some car manufacturers have set themselves the goal to offer attractive new cars for the German market priced significantly below 10,000 Euros. In the meantime this class has become known as the 8,000-Euro class. The pioneer was Renault. In June 2005 they brought out the Dacia Logan which is assembled in Romania and offered it to the German, French and Spanish market. This car offered (almost) the same compartment and trunk dimensions as the so-called Golf class at a significantly lower price. The Dacia

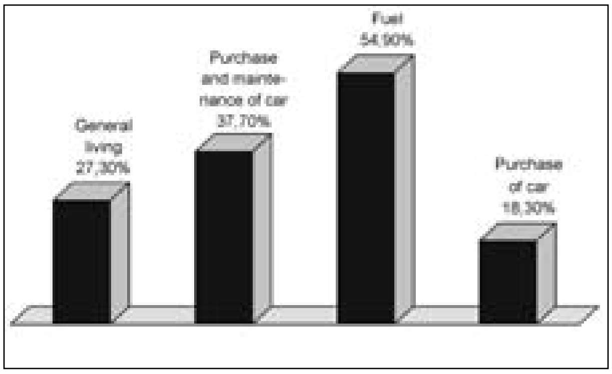


Figure 1: Pattern of cost growth in Germany

Logan is based on the same platform as the Nissan Micra and the Renault Modus. The launch of the Dacia Logan was announced in over 30 countries at the end of 2005. In Germany the list price ranges from 7,200 to 8,200 Euros without any extras. Actually the primary price was targeted to be 5,000 Euros as the “Spiegel” magazine reported in June 2005 [2].

Of course ambitions to offer new cars for little money are appreciated by the consumers. But at the same time the preservation of the high level of vehicle safety available nowadays has to be considered, too. This high level has contributed to a continuous decrease in the numbers of severely and fatally injured people in Germany from the 1970s until today. In 1970 there had been a sad negative record with 21,332 fatally injured road users in Germany. After that, it was possible to reduce this number to 5,482 by the great efforts of all parties. According to estimates made by the Federal Statistical Office this number is still decreasing – and roughly down to 5,400 [3] for 2005. Compared to 1970 this would mean a decline of 75% although the national stock of vehicles increased almost three-fold.

In countries which have not yet reached such a high level of vehicle safety it could be appropriate to set some lower requirements for vehicles. In those countries the vehicles are mostly very old, badly maintained and correspondingly unsafe. In countries like e.g. Germany no cutbacks in the requirements of safety can be tolerated if we do not want to put at risk the positive trend of fewer seriously and fatally injured. In this context also the goals in the White Paper of the European Commission [4] and the European Road Safety Charter [5] have to be taken into account. According to these the number of fatally injured in the EU should be halved by 2010 when compared with 2001. DEKRA is one of the first signatories of the European Road Safety Charter which supports the efforts to achieve this goal on a sustainable basis. In Germany, the subject safety is of much consideration also for low-price cars. The standard equipment of the vehicles includes ABS as well as driver and passenger airbag [6]. However the goals involving crash safety seem to be not always priority number one. The official rating at Euro NCAP for the Dacia Logan is 3 out of 5 possible stars. Current cars of all classes gain 4 to 5 stars [7].

With this background it is of interest to investigate the safety of such vehicles and to publish the results also for the general public. The informed customer can include criteria of vehicle safety on the basis of objective information in his decision whether to buy or not. The German magazine “AutoBILD” picked up this subject first and extensively tested the Dacia Logan. To investigate secondary safety, crash tests have been commissioned at the DEKRA Crash Test Center in Neumünster. These tests were published in April 2005 [8]. A 5 year old, well preserved VW Golf IV was also used to directly provide a comparison with the passive safety of the Dacia Logan. Such a car could also be purchased for a price of 8,000 Euros. The official rating within Euro NCAP for a 1998 VW Golf IV is 4 stars [7].

Additionally another test has been made with a VW Fox which was published in June 2005 [9]. This vehicle is actually a little smaller than the Logan or the Golf but at 9,000 Euro also qualifying for the “under 10,000-Euro class”.

In the following the tests and their results are presented and discussed. In contrast to the publications of “AutoBILD” this will be a mainly technical contribution in which further test results and details will be presented and discussed. Additionally the official Euro NCAP crash test with the Dacia Logan will be included [10].

Crash Tests Conducted with Dacia Logan and VW Golf IV

Task and test configuration

The central task for DEKRA has been the analysis of the safety for the driver and passenger in the Dacia Logan and in the VW Golf IV when involved in the frontal crash according to Euro NCAP. The corresponding article in the magazine “AutoBILD” asked if a new Dacia Logan offers the same passive safety as a used VW Golf IV. Safety relevant differences in the vehicle behaviour and its components should be identified and explained. Some possible variations have also been taken into account during planning of the tests. In addition to the possible technical variations, which are actually marginal, during the execution of such tests further results were obtained possibly due to the influence of production variations in new cars as well as to the condition of the used vehicle. Therefore two

Logans and two Golfs were tested using the same test parameters.

The chosen test configuration complied with the requirements as specified by Euro NCAP – i.e. a 40% offset frontal crash at 64km/h against a barrier, Figure 2. A deformable barrier face is mounted on the rigid barrier at the impact area which deforms in a specified manner under the influence of a force. This impact constellation and the deformation element are also defined in the regulation ECE-R 94 which is standard for vehicle homologation. However, the impact speed used is not 56km/h but 64km/h. According to the philosophy of Euro NCAP this points out differences in the crash performance of the tested vehicles because the relevant test for homologation has to be passed with a good result by all cars.

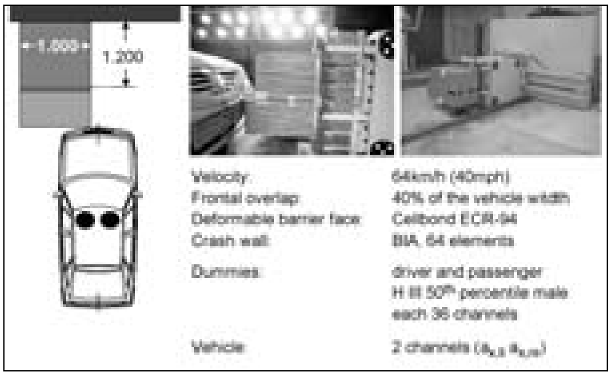


Figure 2: Test configuration

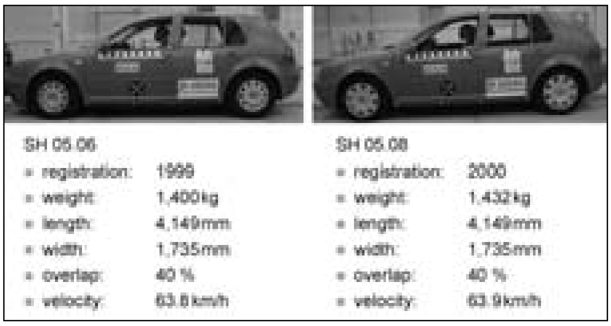


Figure 3: Test vehicles: used VW Golfs IV

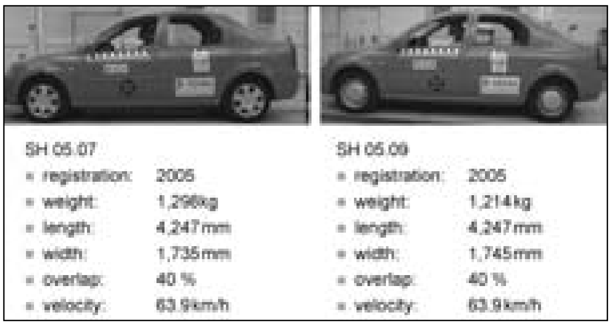


Figure 4: Test vehicles: new Dacia Logans

In addition to the standard test a force-measuring crash wall (manufacturer BIA) was mounted which monitored the magnitude and the sequence of the reaction forces at the impact of the vehicles. Instead of a real driver and passenger anthropometric test devices (dummies) type hybrid III 50^{th} percentile male were used. Both dummies were equipped with 36 channels to measure biomechanical loads. Included are accelerations in the head, chest and pelvis in each three orthogonal directions, the intrusion into the chest as well as further mechanical loads in the neck, femurs, knees and tibia. A uniaxial acceleration sensor was used to measure the deceleration of the vehicle on each side of the vehicle's B-pillar/door sill transition. Each measurement value was recorded with built-in crash-resistant data acquisition units. After the test this data was transferred to an external PC.

Test vehicles

VW Golf IV

Test numbers are used to distinct the tests and the results. For the tests SH 05.06 and SH 05.08 two VW Golf IV were used, Figure 3. The vehicles were licensed in 1999 and 2000 respectively and therefore about 5 years old at the time of the tests. The length of the cars was 4,149mm and the width 1,735mm. The weights including dummies and measurement equipment were 1,400 and 1,423kg resp. The lighter car had been equipped with rims made of aluminium, the heavier one with steel rims. The measured velocities at impact were 63.8 and 63.9km/h resp. The Golf IV is equipped with 3-point seat-belts for driver and passenger. In addition these belt systems have a belt-force limiter. The safety belts are supposed to support the airbags to restrain driver and passenger.

Dacia Logan

Two new Dacia Logans (registration date 2005) were used for the tests SH 05.07 and SH 05.09, Figure 4. The length of the vehicles was 4,247mm and the width 1,735mm. The test weights were 1,214 and 1,298kg resp. The heavier car had been equipped with air conditioning and a bigger rim-wheel combination. Both vehicles impacted at 63.9km/h. The Logan is equipped with 3-point seat-belts for driver and passenger without a belt-force limiter. Frontal airbags are also part of the restraint system.

Impact behaviour

Vehicle structure

All four test vehicles showed a generally similar behaviour by the structures during impact. A detailed inspection showed that the deformation at the Golf appeared a little more harmonic and steady. No differences could be recognized with the two almost identical sequences of the measured forces at the crash wall. However the deceleration of the Golfs took a little longer than the deceleration of the Logans and the peak values of the Golf were lower than the respective values of the Logan. The survival space for the occupants remained adequate. The A-pillars suffered only marginal distortion at the impact side. The displacement of the A-pillars was measured 100mm beneath the window aperture (top) and 100mm above the sill (bottom). The displacement for the Logans was between 7mm at the top and 29 and 30mm resp. at the bottom. For the Golfs it was between 7 and 8mm resp. at the top and 43 and 46mm resp. at the bottom (see Table 1).

The rearward vertical displacement of the upper steering column was 2 and 23mm resp. for the Logans and 27 and 39mm resp. for the Golfs. The displacement at the lower steering column was 12 and 14mm resp. for the Logans and 52 and 65mm resp. for the Golfs.

		VW Golf		Dacia Logan	
		SH 05.06	SH 05.08	SH 05.07	SH 05.09
Door opening forces [kN]					
Driver door	opening	242	137	**blocked**	**blocked**
	45°	641	631	458	171
passenger door	opening	76	75	33	21
	45°	55	45	30	24
Door left backseat	opening	36	52	42	25
	45°	53	56	48	33
Door right backseat	opening	70	56	24	26
	45°	75	50	36	28
Displacements [mm]					
Upper A-pillar		8	7	7	7
Lower A-pillar		46	43	29	30
Gas pedal		36	83	9	14
Brake pedal		80	87	54	21
Clutch pedal		135	129	**222**	170
Upper steering column		27	39	2	23
Lower steering column		65	43	14	12

Table 1: Door opening forces and vehicle distortions

Further measurements were made. The rearward displacement of the pedals for the Logan was: brake 21/54mm, clutch 170/222mm, throttle 14/9mm. For the Golfs: brake 87/80mm, clutch 129/135mm, throttle 83/36mm. The pedals released mechanically because of the impact loads. This technique is nowadays common and reduces the bruise loads on the feet and lower extremities. The Logan did not have such a mechanism.

The doors on the passenger side of all four vehicles could be opened using normal hand force as well as the back doors on the driver’s side. But there was a significant difference when trying to open the driver’s doors. While the doors of the Golfs could be opened with moderate hand force (242kN/137kN), the doors of the Logan had to be opened using a crowbar. The reason for this was clamping of the lock mechanism of the pin-type lock. Unlike the Logan the Golf is equipped with the bracket-type lock commonly used today which prevents such clamping occurring.

Another positive effect observed at all tests has been that no door opened during impact. This is required according to technical standards to prevent passengers from being thrown out of the car. It is furthermore required that at least one door per seat row can be opened without using any tools. As one door could be opened after the test with the Logan this requirement was fulfilled, but a door which can not be opened easily after a crash complicates the care and rescue of injured people – in this case especially for the driver.

Restraint systems

The airbags in the Golfs worked in a normal manner at both tests. This is shown by a firm inflation of the airbag while the passengers are still moving forward relative to the car due to their inertia. In this early phase the passengers are already restrained by the belts. To lower the peak loads for the upper body regions belt-force limiters are activated at a certain trigger force. Such a limitation of the restraint force is common for today’s seat-belts in combination with airbags. That is because the fully deployed airbag can protect the head and upper body and therefore support the restraint efficiency of the belt. In the further sequence the airbag is further compressed by the passengers which are still moving. At this point, airbag gases escape through exhaust vents. During the design of a new vehicle the restraint systems are accurately coordinated to achieve best results which means passenger loads are kept below the biomechanical limits and there is no steering wheel contact with the body or the head. The same applies to the passenger side.

At both tests with the Logan, a behaviour was observed which was classified as unusual. The airbag gases escaped very early. At this early point the airbag could not really support the seat-belts. Significant interaction of the airbag and the passenger could be seen fairly late and during a phase in which the airbag is already droopy because of the escaped gases. Therefore the seat -belts basically restrain the passengers with the result that the measured belt forces are higher for the Logans than for the Golfs.

No bottoming out of the airbags could be observed for either the Golf or the Logan.

Dummy loads

As described before, the survival space for the Golf as well as for the Logan remained almost intact. This adequately complies with an essential part of the basic principle of secondary safety while the measured dummy loads determine the vehicle's safety performance. Firstly, consideration is given to some common used test results of the dummies. Afterwards the dummy loads especially of interest for Euro NCAP will be analysed.

Common used load data

Driver

The technical regulations specify the Head Injury Criterion HIC as well as the highest resulting head acceleration during a time interval of 3ms (a_{3ms}). The HIC is a nondimensional value with a limit of 1,000. The resulting head acceleration has the limit a_{3ms}=80g. If these values are exceeded irreversible injury of the brain and the skull are very likely. The values for the Golf (HIC=358 and 393 resp. and a_{3ms}=45g and 47g resp.) are far below the biomechanical limits, Table 2. This has been a trend-setting feature of vehicles of this generation. Mandatory requirements for these good test results consist of accurately coordinated restraint systems like the safety belt with belt-force limiter and airbag. With a HIC of 943 and 855 resp. and a_{3ms}=79g and 67g resp. the head-load values for the Logan are very high and very close to their limits. This indicates a correspondingly higher risk of injury.

Driver Loads	VW Golf		Dacia Logan	
	SH 05.06	SH 05.08	SH 05.07	SH 05.09
Head HIC	358	393	943	855
Head a_{3ms}	45.15g	46.87g	78.49g	67.34g
Neck M_Y	33.15Nm	29.76Nm	9Nm	22.7Nm
Chest deflection	26.72mm	24.42mm	27.72mm	26.64mm
Chest a_{3ms}	41.8g	38.05g	41.8g	48.46g
Pelvis a_{3ms}	40.6g	39.21g	40.6g	51.08g
Upper femur F_z right	1.94kN	1.75kN	1.94kN	1.84kN
Upper femur F_z left	1.68kN	1.38kN	1.68kN	1.25kN

Table 2: Driver loads

The vertical neck momentum (tension/extension) is used to rate the neck stresses and strains. For the Golfs the measured values were M_y=33Nm and 30Nm resp. and for the Logans M_y=9Nm and 23Nm resp. The relevant limit is 57Nm which is significantly higher than the measured values. Important test results by which to assess the chest loads are the resulting chest acceleration a3ms and the geometrical deflection of the chest. The relevant limits are a_{3ms}=60g and s=50mm resp. The test results for the Golfs were a_{3ms}=42g and 38g resp. and s=27mm and 24mm resp., and for the Logan a_{3ms}=51g and 49g resp. and s=31mm and 27mm resp. These values are far below the relevant limits. For the pelvis area the a_{3ms}-value is used, too. Here the limit is 60g. With results of a_{3ms}=41g and 39g resp. for the Golfs and a_{3ms}=53g and 51g resp. for the Logans these values are not critical. Finally the maximal compressive force of the femur will be addressed. The usual limits are 10kN although some literature mentions 8kN. Both the Golfs (left femur: 1.81kN and 1.75kN resp. and right femur: 2.16kN and 2.25kN resp.) and the Logans (left femur: 1.27kN and 0.97kN resp. and right femur: 1.4kN and 1.14kN resp.) are on the same level and far below the limits.

Overall, the reported values show, that the head of the driver of the Logan was exposed to significantly high loads. This means there would be a high risk of injuries of the head. For other body regions the differences between the Logans and the Golfs are not significant and always below the biomechanical limits.

Passenger

A high level of stresses and strains can be observed when looking at the test results for the head of the Logan's passenger. In both tests the limit for the HIC has been exceeded (HIC=1,197 and 1,016 resp.). The limit for the resulting acceleration of 80g has been exceeded once (a_{3ms}=83g) and the other time almost (a_{3ms}=75g),. The corresponding values for the Golfs (HIC=270 and 172 resp. and a_{3ms}=40g and 32g resp.) are far below those of the Logans. The other body regions of the passenger have also been measured by reference to the load variables already stated. Those are more or less on the same level for both vehicles and below the biomechanical limits.

Passenger Loads	VW Golf		Dacia Logan	
	SH 05.06	SH 05.08	SH 05.07	SH 05.09
Head HIC	270	172	1197	1016
Head a_{3ms}	39.67g	32.26g	82.53g	75.16g
Neck M_Y	21.22Nm	27.43Nm	28Nm	33Nm
Chest deflection	31.98mm	31.24mm	38.47mm	37.56mm
Chest a_{3ms}	33.5g	30.31g	41.71g	41.01g
Pelvis a_{3ms}	37.51g	37.33g	52.52g	46.69g
Upper femur F_Z right	1.36kN	1.49kN	0.99kN	1.21kN
Upper femur F_Z left	2.37kN	1.97kN	1.16kN	1.4kN

Table 3: Passenger loads

Rating according to Euro NCAP

Additionally to the already mentioned test results the dummies yielded further measurements for the knee and tibia. All of the collected data of summarized to calculate and display the body-related injury risk according to Euro NCAP. Manikins are used to provide easy and clear information to the customers. The injury risks for the head, chest, pelvis, femur, tibia and feet are presented visually by using different segments. Additionally, the feet of the driver show the effects

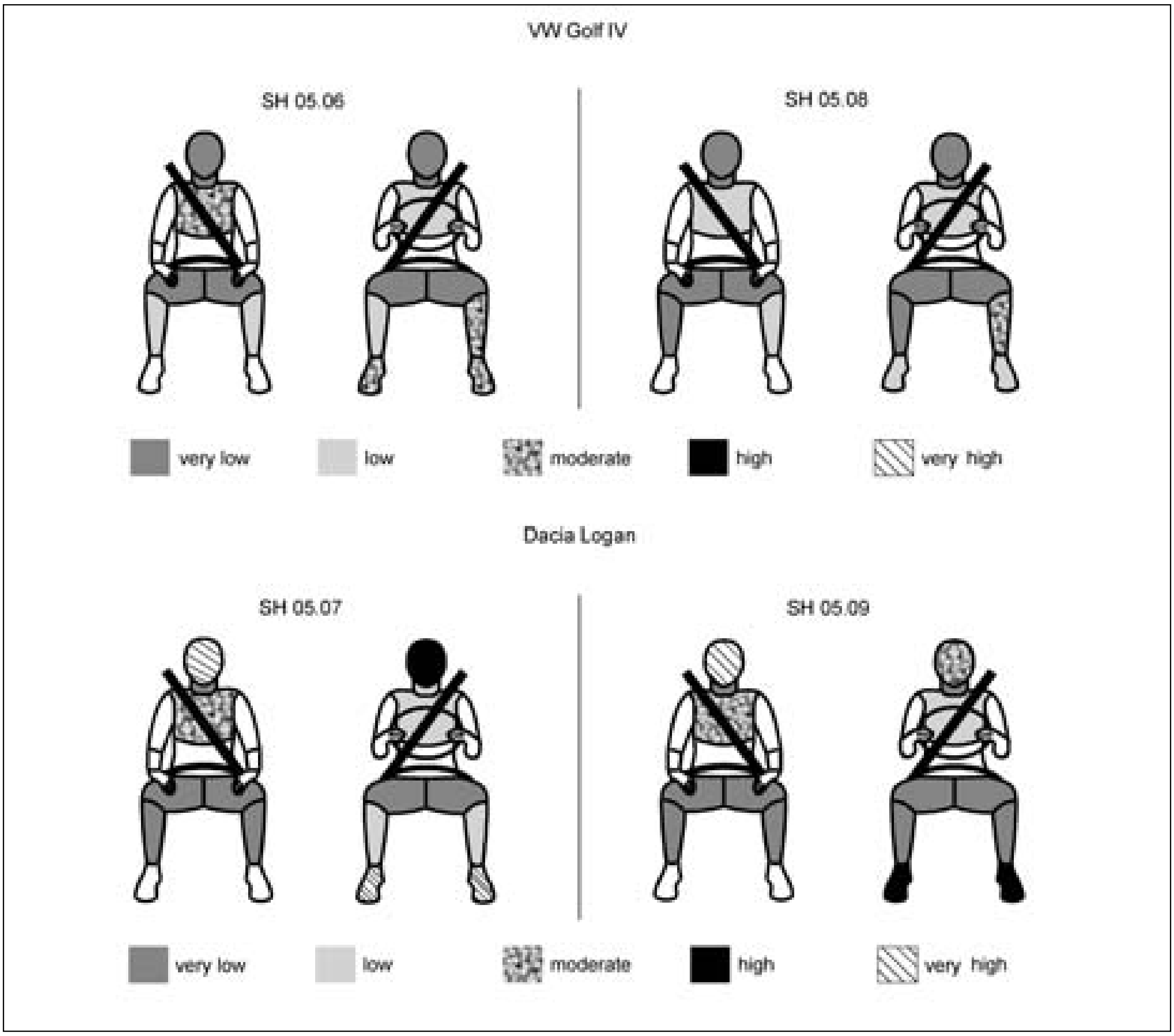


Figure 5: Driver and passenger injury risks as results of the crash tests conducted with Dacia Logan and VW Golf IV

of pedal intrusions. The classification is made by a mathematical algorithm using the dummy measurements as described in the official Euro NCAP protocol [11]. This calculation will be explained in detail considering the head as example. Furthermore the score generated from dummy data may be modified where the protection for different sized occupants or occupants in different seating positions, or when involved in accidents of slightly different severity, can be expected to be less effective than that indicated by the dummy readings or deformation data alone. In any single body region, the score may be reduced by a maximum of up to two points. No modifier has been used by DEKRA in these calculations.

The different segments of the manikins reflect the injury risks, see Figure 5. According to Euro NCAP the loads for the femur and knee were consistently low. The injury risk for the tibia were rated from very low to moderate and for the chest from low to moderate. Also some variances for the same type of car can be seen because of slight differences in the dummy loads. This can be seen particularly clearly if a value is located between two risk groups, e.g. between a low and a moderate risk of injury. A low to moderate injury risk has been assessed for the feet of the driver in the Golf. For the Logan it was rated moderate to high.

Singularity of the head rating

The described high risk of injury for the driver and passenger of the Logan is shown by the different segments of the Euro NCAP manikin. While the Golf was rated with dark grey heads for very low injury, the Logan was assigned with different heads which mean a high or even a very high risk of injury for the head. During the analysis of the test results a discussion came up because the DEKRA test results for the head differed from the official Euro NCAP ones [10]. In this context the Euro NCAP algorithm to calculate the results has to be considered.

Each body region (head and neck, chest, pelvis, femur and knee, tibia and feet) can be awarded a maximum of 4 points. The requirement is that the load of each body region is below or equal the so-called "higher performance limit". The higher performance limit refers to the car not to the occupants. The corresponding risk of injury is very low and displayed by a dark grey body region. The worst rating is 0 points and awarded if one dummy measurement of the body region is equal or over the "lower performance limit". The corresponding risk of injury is very high. Within these two performance limits a "sliding scale" relates the measured value and the awarded points. Within the 0 to 4 achievable points there are further fragmentations which separate the injury risk into low, moderate and high. If one or more loads on one body region result in a rating lower than 4 the worst rating is used for the total result and for the different segments of this body region of the manikin.

To rate the injury risk for the head the resulting acceleration a3ms and the HIC are used. The lower performance limits are HIC=1,000 and a_{3ms}=88g, the higher performance limits are HIC=650 and a_{3ms}=72g. For the Golfs all measured values were lower than the higher performance limit and classified as very low. This can be seen from the dark grey heads for both driver and passenger. The measured loads for the driver dummy of the Logan were HIC=943 and 855 resp. and a_{3ms}=78.49g and 67.34g resp.. These values are slightly lower than the lower performance limit of HIC=1,000 and a_{3ms}=88g but inside the sliding scale. Taking the worst rating these values result in amoderate risk of injury and ahigh risk of injury respectively. For the head of the passenger dummy the measured values were HIC=1,197 and 1,016 resp. and a_{3ms}=82.53g and 75.16g resp.. In both tests the lower performance limit for the HIC of 1,000 was exceeded. This means a high risk of injury for the head. As mentioned above, the risks of injury to the head revealed by the tests have been published to a partial extent in the magazine "AutoBILD". In the meantime the official result of Euro NCAP has also been released. In this the head of the driver and passenger of the Logan has been rated with a very low risk of injury which is reflected by a dark grey head for the manikin [10]. This rating results from a special condition in the Euro NCAP protocol which requires a hard contact with the head to actually rate the risk of injury to the head as high. This hard contact is recognized if the peak value of the resulting acceleration of the head is over 80g. If this is not the case the risk of injury for the head is assessed as "very low" – irrespective of the HIC.

Under this special condition the head injury risk would have been rated high (red) only once –

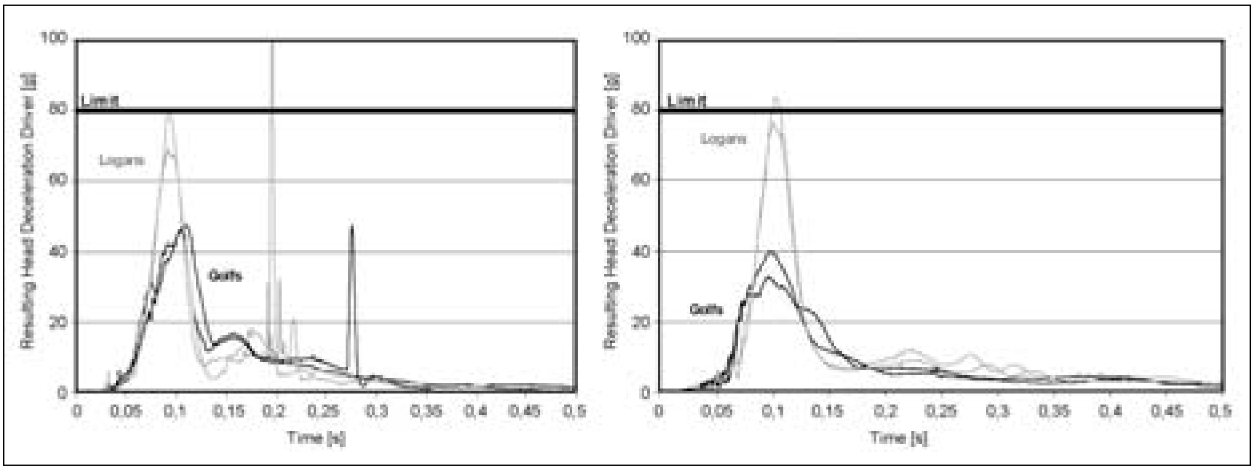


Figure 6: Head decelerations for driver and passenger for all tests conducted with Dacia Logan and VW Golf IV

namely for the passenger of test SH 05.07 (a_{3ms}=82.53g/HIC=1,197). The passenger in the second test with a peak acceleration of a max=76.37g which is below 80g would have received a dark grey head despite an HIC of 1,016 and a_{3ms}=75.16g,. In the face of these high values relative to the biomechanical limits as well as the higher values for the Dacia Logans when compared to the Golfs this special condition was not applied by DEKRA for the rating results published by Auto BILD and the HIC was used to rate the passenger. This resulted in a very high head rating for the second test, too.

The measured maximum values of the resulting head acceleration of the Logan driver were a_{max}=79.97g for test SH 05.07 (HIC=943/ a_{3ms}=78.49g) and amax=79.1 g (HIC 855/a_{3ms} =67.34g) for test SH 05.09. If the special condition had been applied the rating would have been a very low risk of injury. Regarding the test SH 05.07 the small gap of merely 0.03 g would have been decisive for this unrealistic rating. Here too, the special condition was not appplied by DEKRA and the rating was made by using the HIC value. This resulted in a high risk of injury for test SH 05.07 and a moderate risk of injury for test SH 05.09.

During the discussion this approach was considered to provide the most consistent option within the limits of the rating possibilities representing the real risks of injury to the head. This applies also to the absolute value of the loads and on the other hand to the direct comparison with the low values for the Golf. The test results for the Logan represent a marginal case which should be considered in the further development of the official Euro NCAP-protocol.

Crash Test Conducted with VW Fox

Finally, consideration of the results of a frontal test involving a new VW Fox confirms the level of secondary safety which can be already achieved with vehicles in the lower compact class. The Fox is equipped with a seat-belt system with seat-belt pretensioner and seat-belt-force limiter both for both driver and passenger. In a very early phase of the crash the seat-belt pre-tensioner reduces the belt slack. Additionally the Fox is equipped with an airbag for driver and passenger.

The test vehicle weighed 1.238kg. Its length was 3.828m and width 1.660m. In accordance with Euro NCAP the offset was 40 % and the test velocity 63.9km/h. A harmonic deformation of the vehicle crumple zone could be observed during the crash. The passenger cell remained almost intact and the survival space for the occupants remained fully intact. At the driver's side the A-pillar distorted to an insignificant degree. The rating according to Euro NCAP was carried out by DEKRA without using modifiers. The loads on the passenger were consistently very low (all body parts dark grey). For the driver all body parts apart from the chest and the left tibia have been rated a very low risk of injury (dark grey). The chest and tibia have been rated a low injury risk, see Figure 7.

With these results the VW Fox meets the level of the current VW Golf V. The Golf V was rated 2004 with the maximum result of 5 stars [7].

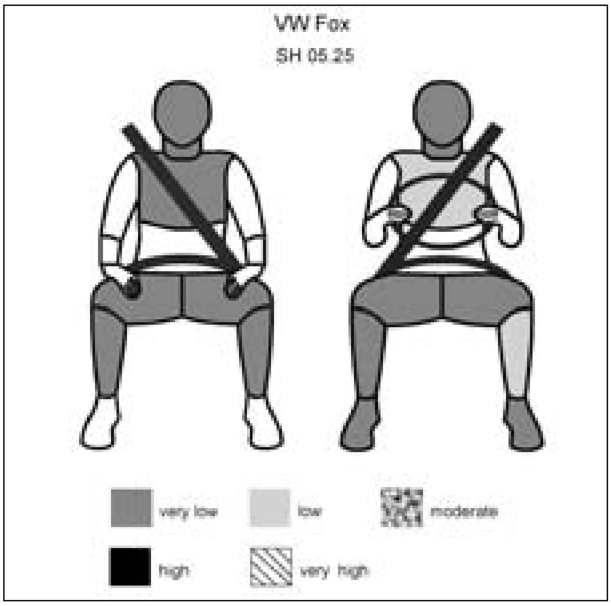


Figure 7: Driver and passenger injury risks as results of the crash test with a VW Fox

Summary and Prospects

Assessing the safety rating for the occupants of vehicles is a complex task. The first consideration must be the safety equipment of the car itself. After that the interaction of the restraint systems and the body structure as well as the behaviour of the occupants during crash loads is decisive.

When a frontal impact occurs it is necessary for the structure of the front end to transform as much impact energy as possible into deformation by controlled and harmonic crumpling. The survival space located behind the front end should remain almost intact. It is also beneficial if the pedals intrude only marginally into the footwell and transfer only low stress to the feet. Inside the passenger cell the occupants are decelerated by the restraint systems. At this stage it is important to keep the loads on passengers below the critical limits above which there is a significant risk of injury being suffered. An early and sustained deceleration of the vehicle is beneficial. Hereby the passengers should participate as early as possible. Seat-belt pre-tensioners are state-of-the-art. The expansion of the belt under the load enables a further forward movement of the occupants. This lowers the deceleration loads still further so that seat-belt force limiters can optimize the controlled forward displacement. In a subsequent stage airbags support the seat-belts and prevent injury by protecting the occupants against impacts with the steering wheel or the dashboard.

The frontal crash tests produced a multitude of results which may not always lead to the same good or even very good rating. But as described with the Euro NCAP protocol they allow a clear overall rating of the occupant safety to be made and also a comparison between single vehicles. Therefore the tests were conducted in accordance with Euro NCAP requirements, namely with a velocity of 64km/h and an offset of 40% and gave the following insights:

The behaviour of the body of the Dacia Logan was positive. There was no collapse and the survival space for the occupants remained intact. A negative finding was that the driver doors could only be opened after the test with the use of tools and considerable force. The reason for was a jammed pin-type door lock. This may complicate the recovery and rescue of injured people. Furthermore the high head loads experienced by the driver and the passenger are criticised. The reason for the high loads is probably less than ideal coordination of the seat-belts and the airbags. This is also indicated by the high measured seat-belt forces which means that the seat-belts are providing the main restraint for the passengers. The airbags also show an unusual behaviour. They deflated relatively early before contributing to the restraining of the passengers. Furthermore the rearward movement of the rigid pedals leads to higher loads on the driver’s feet.

The Golf IV showed several significantly better results in the direct comparison. In the Golf the survival space also remained intact and the doors could be opened without any problems. All loads could be rated according to Euro NCAP procedure as very low to moderate. Especially the head loads were at a significantly lower level compared to those experienced in the Logans. The seat-belts equipped with seat-belt force limiters and the airbags gave a very well coordinated performance. The release mechanism of the pedals reduces the risk of bruise loads to the driver´s feet.

The VW Fox showed a better structure performance in the direct comparison with the Golfs and the Logans. The seat-belts, equipped with force limiter and pre-tensioner, combined with the airbags contributed to the low dummy loads. Consequently, the improvement in secondary safety of current new cars is there to be seen by all. Recently, occupant safety is no more a privilege of middle- or upper-class cars.

The improvement of vehicle safety is nowadays a common European goal. Against the background of accident events and vehicle population the Dacia Logan can be seen as a real economic alternative in some European countries. It could contribute to the replacement of old, badly maintained vehicles and therefore increase the general level of vehicle safety. Indeed this basically applies to Germany and other Western Europe countries, too. But in these latter regions the vehicle population is not that extremely outdated as it is in some countries of Eastern Europe or local Southern Europe. As the test results have shown for vehicles in the "8000-Euro class" a well maintained used car equipped with the relevant safety-related features can be an equal alternative. It is for the consumer to consider the importance of vehicle safety when deciding if he prefers a new low-cost vehicle or a used vehicle that could be more safe. If vehicle safety is of priority 1 and size does not matter, new cars in the "8000-Euro class" are not available but new vehicles can be purchased in the "10,000-Euro class". The achieved level of vehicle and road safety in Germany and other European countries must not be jeopardized. It has to be extended still further to keep on lowering the still unacceptable high number of severe or fatally injured people. That is why the requirements for the safety of new vehicles may not be lowered. On the contrary, the trends towards more safety have to be recognized and strengthened. Finally we must accept that this will not happen for free.

In this context consumer crash tests like those organised by Euro NCAP in addition to crash tests carried out for public magazines are welcome. This contributes to more interest being taken in secondary safety by the consumers. The consumer can include safety provisions based upon objective information when considering his buying decision. The tests made by DEKRA on behalf of "AutoBILD" have also shown that there is a further need for professional discussions to be held on the subject of the rating scheme.

References

[1] ADAC (ed.): Mobilität im Jahr 2020. Trends, Herausforderungen und Lösungsstrategien. Article #283112.1 ADAC e. V., München 2003

[2] http://www.spieqel.de/auto/aktuell/0,1518,302300,OO.html: 5000-Euro-Auto geht an den Start. Spiegel ONLINE – June 2nd 2004

[3] http://www.destatis.de/presse/deutsch/pm2005/p5150191.htm: Road accidents – prospect 2005

[4] White Paper submitted by the Commission on September 12th 2001: European transport policy for 2010: time to decide (2001) 370, September 12th 2001

[5] European Road Safety Action Programme – halving the number of road accident victims in the European Union by 2010: a shared responsibility, EU Commission (2003) 311, February 6th 2003

[6] http://www.dacia-loqan.de, official homepage of the Dacia Logan

[7] www.euroncap.com/How safe is your car?

[8] AutoBILD #15 from April 15th 2005, p. 40-44

[9] AutoBILD #22 from June 3rd 2005, p. 8-11

[10] www.euroncap.com/How safe is your car?/ Dacia Logan

[11] www.euroncap.com/Test Procedures Explained

K. Okamura, K. Mori
National Research Institute of Police Science, Chiba, Japan

Y. Nishida
Institute for Traffic Accident Research and Data Analysis, Tokyo, Japan

Restraint Use Patterns for Injured Children in Japan

Abstract

Since the compulsory use of child restraints for children up to 5 years of age was introduced in 2000, restraint use among younger children has increased significantly. However, the observed rate of child restraint use plateaus at around 50%, and apparently little spillover effect has been found for older children who are not covered by the law. This report examines the restraint use patterns for children who were injured in cars in relation to driver and child passenger characteristics. Univariate and multivariate analyses were conducted to describe the association between the outcome measure (the proper use of restraints for children) and relevant variables. Better ways for parents and caregivers to improve the use of restraints for children are also discussed.

Introduction

Since the compulsory use of child restraints was mandated in 2000, the use of child restraints among Japanese child passengers has increased markedly. However, there is also evidence showing that many children are still unrestrained in cars and more could be done to improve this situation. Results of the latest survey conducted in 2005 show that the observed rate of restraint use among infants up to 1 year old was 74%, but this figure falls as the age of the children increases – 49% for children 1 to 4 years old and 30% for 5 year olds. Overall, just half of the children younger than 6 years of age (the age group targeted by the law) were appropriately restrained [1]. Of greater concern is that the proportion of child occupants observed to be appropriately restrained had begun to slightly decline in 2003 and has since leveled off. This occurred only three years after the law was enacted. Furthermore, the use of child restraints has apparently not expanded among older children who are not covered by the law, but still too small to be restrained by adult safety belts.

The problems are twofold: (a) the use of child restraints among children covered by the law is not sufficiently high, and (b) restraint use also remains low for other passenger age groups – older children and adults. The latter point has been raised for two reasons. First, if younger children or their parents became accustomed to using child restraint systems (CRS), they would continue to use CRS even when the children become older than 5 years old, until they typically outgrow booster seats. Secondly, it is not realistic to expect a miraculous rise in CRS use to occur only among young children, while the majority of older children and adult passengers in rear passenger seats are not restrained. In Japan, the rate of safety belt use among rear seat passengers is generally very low at 8% [1]. This apparently reflects the current law (or lack of regulation) in Japan where there are no punitive measures for not wearing safety belts while riding in the rear seats. This contrasts sharply with the high rate of using safety belts among drivers and front-seat passengers (92% and 80%, respectively [1]).

The present study attempts to identify the factors associated with proper use of restraints for children, and suggests recommendations for promoting the use of child restraints with a focus on the role of parents and caregivers.

Methodology

Database

The national traffic accident database of the National Police Agency (NPA) was used for this study. The NPA database consists of all police-reported accidents resulting in the injury or death of at least one person. For each accident, a minimum of 67 items of data is recorded, such as driver characteristics, collision details, environmental information. Passenger information is only compiled in cases of reported injury. At least 21 items of data items are typically recorded for each passenger involved in an accident. However, the NPA database does not provide information on passengers who do not sustain injury. Therefore, uninjured child passengers are not included within the scope of the present study.

Data coding of child restraint use patterns

The outcome measure of the present study is the proper use of restraints by child passengers. Information on the use of child restraints in the NPA database is recorded as follows: (1) appropriate CRS use, (2) CRS misuse, (3) restrained by safety belts, (4) unrestrained, (5) exempted due to illness and other reasons, and (6) unknown. Of these, (5) and (6) were excluded from the analysis. Appropriate CRS use refers to use of the appropriate safety device based on the weight and height of a child, and seating in an appropriate position within the vehicle [2]. CRS misuse is interpreted as gross misuse resulting in a child being ejected from the CRS due to an accident, and is typified by the loose attachment of safety belts to the CRS and loose harness straps.

Parameters (1) to (4) were re-coded separately for younger children (up to 5 years old) and older children (6 to 12 years old) as shown in Table 1. For younger children, cases where they were appropriately restrained by CRS were re-coded as ‘properly restrained’, and others (parameters (2), (3) and (4)) were re-coded as ‘not properly restrained’. For older children, cases where they were appropriately restrained by CRS or restrained by safety belts (parameters (1) and (3)) were re-coded as properly restrained. The use of safety belts by children younger than 13 years of age may be considered a premature graduation from CRS and therefore inappropriate. However, since the purpose of this study is to investigate the use of child restraints at the time of an accident in conjunction with the current law, parameter (3) was re-coded as properly restrained for this age group.

	Outcome measure	
	Properly restrained	Not properly restrained
0-5 years olds	Appropriate CRS use	CRS misuse Unrestrained Restrained by safety belt
6-12 years olds	Appropriate CRS use Restrained by safety belt	CRS misuse Unrestrained

Table 1: Re-coding of child restraint use

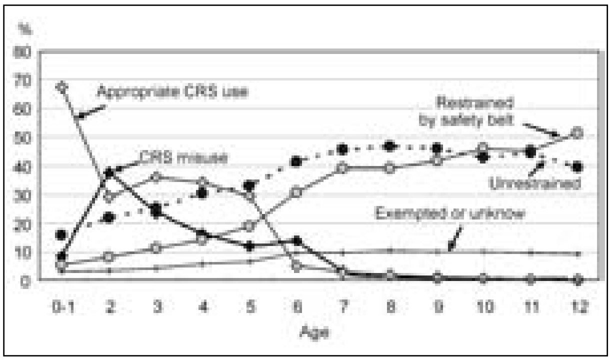


Figure 1: Restraint use patterns in percentage by age of children injured or killed

Data sets

Original data set

The following cases were extracted from the NPA database to form a separate data set: accidents in which child passengers up to 12 years old were injured or killed during the years 2004 and 2005 in privately owned passenger cars. This data subset is called the original data set. Large vehicles, school buses, taxis, and rented cars were excluded. This original data set includes information on 47,283 children who were injured or killed in car accidents.

Children up to 5 years old are the target group of compulsory CRS use under the current law. Older children 6 to 12 years old, covering all primary school-age pupils, were also included for analysis. Figure 1 shows the restraint use pattern for children who were injured or killed as obtained from the original data set. The percentage of appropriate CRS use is relatively high only for infants up to 1 year old, but drops below 40% for children 2 to 5 years old. Fewer than 5% of the children injured or killed who were at least 6 years old used CRS appropriately. Conversely, the percentage of children who were restrained by safety belts or not restrained at all increases with the children’s age.

Not-at-fault rear-end collision data set

Since the NPA data provides information only on injured passengers, it is quite possible that certain types of accidents are overrepresented while others are underrepresented in the original data set. For example, a previous data analysis of Japanese child occupants showed that a higher proportion of injured child passengers were found to be unrestrained in head-on collisions and single-vehicle accidents than in rear-end collisions [3]. It is assumed that head-on collisions and single-vehicle accidents are overrepresented in the data due to the high speed at impact, thus reflecting a higher incidence of injury to child passengers, which results in higher percentage of the injured child passengers found to be unrestrained. This is not necessarily due to a lower rate of CRS use among those involved in head-on collisions. The main focus of the present study is to identify the demographic and behavioral characteristics of occupants associated with the proper use of restraints under existing regulations. To this end, it would be best to eliminate the effects of certain factors if they excessively influence data representation.

Drivers who were involved in rear-end collisions as the party least responsible can be considered a pseudo-sample of drivers who happened to be involved in an accident "by chance". Admitting that this is only a rough estimate, much of the bias influencing the use of child restraints could be eliminated by focusing on those involved in a rear-end collision, thus making it possible to identify the factors associated with the use of restraints by children. It is indeed true that this estimate still suffers from selection bias, for example, inflated restraint use rate, and this is discussed later in this paper. This "quasi-not-at-fault driver subgroup" data set was created by extracting the drivers whose vehicles were struck by another vehicle in a rear-end collision as the party least responsible, together with information on child passengers. This data subset is called the not-at-fault rear-end collision data set. This data set consists of 21,352 pairs of drivers and child passengers, accounting for 45.2% of the cases in the original data set. Almost all (99.3%) drivers were judged to assume no legal responsibility for an accident, and 90.2% of the drivers involved were actually braking to stop their cars uponrealizing the imminent danger. Nine children were killed within 24 hours of an accident (0.04%), and 63 were seriously injured (0.3%), meaning that virtually all the children suffered minor injuries (99.7%) – typically neck sprain or whiplash injury.

Data analysis

Based on the not-at-fault rear-end collision data set, Pearson's chi-square and t-statistics were used to compare the demographics of occupants (age, gender, and license status), characteristics of travel (purpose, time of day, and day of the week), and other relevant variables (use of a safety belt by the driver, seating position, and total number of occupants) to the outcome measure (the proper use of restraints for children). After univariate associations with outcome were calculated, correlation coefficients (r) were computed to check the relationship between independent covariates of interest. Logistic regression was then applied to compute the odds ratio, adjusted for possible confounding variables.

Results

Univariate analysis

Table 2 summarizes univariate association with the outcome measure for younger children (up to 5 years old). A significant association was found between the outcome and time of day, day of the week, driver gender, driver age group, license status, purpose of travel, use of a safety belt by the driver, number of occupants, and the age of children. No significant association was found regarding the type of car and seating position of the children. Moreover, no association was found regarding the gender of children, results of alcohol tests, and the use of mobile phones while driving (not shown in the tables). Further detailed information on the occupants is not available, such as how many adults and children were seated together in a car.

Table 3 summarizes univariate association for older children (6 to 12 years old). A significant association was found between the outcome and day of the week, driver gender, driver age group, type of car, purpose of travel, use of a safety belt by the driver, number of occupants, and the seating position and age of the children. No significant association was found regarding the time of day and driving license status.

Multivariate analysis

In order to simultaneously adjust for possible confounders, multivariate analysis was conducted. Based on univariate analysis, any variable whose univariate test yielded a p-value <0.05 was included in the multivariate model. Table 4 and Table 5 show adjusted odds ratio (OR) and a 95% confidence interval (CI) for younger and older children, respectively.

As shown in Table 4, six variables were significant predictors of the proper use of restraints by younger children, when adjusted for the effects of other variables. The OR of proper restraint use was 14% lower at night compared with daytime (OR=0.86). Drivers aged 50 and older were less likely to restrain children properly, while drivers in their 30s

Variables			Properly restrained	Not properly restrained	x^2 or *t*
Time of day (%)	Day		81.0	77.7	X^2=16.80[3]
	Night		19.0	22.3	
		N	4945	4922	
Day of week (%)	Weekdays		57.8	52.9	
	Weekends/ bank holidays		42.2	47.1	
		N	4945	4922	
Driver gender (%)	Man		37.1	42.3	X^2=28.21[3]
	Woman		62.9	57.7	
		N	4945	4922	
Driver age group (%)	29 and under		29.0	31.7	X^2=56.55[3]
	30-39		55.0	57.0	
	40-49		9.1	7.2	
	50-59		4.1	2.5	
	60 and older		2.8	1.5	
		N	4945	4922	
Driving license status (%)	Valid		99.9	99.8	X^2=5.45[1]
	Notvalid		0.1	0.2	
		N	4945	4920	
Type of car (%)	Passenger car		69.9	68.2	X^2=3.36
	Mini car <660cc		30.1	31.8	
		N	4945	4922	
Purpose of travel (%)	Commuting		1.8	1.6	X^2=24.75[3]
	Business		0.6	0.7	
	Leisure		14.3	17.7	
	Shopping		33.2	32.3	
	Visit		17.8	17.8	
	Escort		8.3	8.0	
	Other private		24.0	22.0	
		N	4945	4920	
Driver belt (%)	Belted		99.2	97.9	X^2=30.27[3]
	Unbelted		0.8	2.1	
		N	4919	4898	
Seating position of child (%)	Front seat		25.3	26.3	$X^2$1.22
	Rear seat		74.7	73.7	
		N	4926	4876	
Number of occupants	Average (SD)		3.04 (0.96)	3.41 (1.15)	*t*=17.3[3]
	Mode		3	3	
		N	4945	4922	
Child age	Average (SD)		2.28 (1.46)	3.06 (1.39)	*t* =-27.09[3]
	Mode		1	2	
		N	4945	4911	
[1] p<.0.5, [2] p< 0.1, [3] p<.00.1					

Table 2: Univariate analysis of proper restraint use for younger children (up to 5 years old)

Variables			Properly restrained	Not properly restrained	x^2 or *t*
Time of day (%)	Day		73.2	73.1	X^2=0.02
	Night		26.8	26.9	
		N	5044	4959	
Day of week (%)	Weekdays		45.8	41.5	X^2=19.22[3]
	Weekends/ bank holidays		54.2	58.5	
		N	5044	4959	
Driver gender (%)	Man		34.5	41.7	X^2=57.88[3]
	Woman		65.7	58.3	
		N	5044	4959	
Driver age group (%)	29 and under		6.0	5.3	X^2=28.34[3]
	30-39		56.8	53.2	
	40-49		29.7	34.2	
	50-59		3.5	4.0	
	60 and older		3.9	3.3	
		N	5044	4959	
Driving license status (%)	Valid		100.0	99.9	X^2=2.70
	Notvalid		0.0	0.1	
		N	5044	4959	
Type of car (%)	Passenger car		66.6	69.5	X^2=10.05[2]
	Mini car <660cc		33.4	30.5	
		N	5044	4959	
Purpose of travel (%)	Commuting		1.1	0.9	X^2=81.77[3]
	Business		0.7	0.5	
	Leisure		16.0	22.4	
	Shopping		31.5	30.0	
	Visit		16.5	16.8	
	Escort		11.5	11.0	
	Other private		22.8	18.4	
		N	5044	4959	
Driver belt (%)	Belted		99.9	98.1	X^2=79.32[3]
	Unbelted		0.1	1.9	
		N	5035	4946	
Seating position of child (%)	Front seat		59.0	8.5	X^2=2842.10[3]
	Rear seat		41.0	91.5	
		N	5036	4952	
Number of occupants	Average (SD)		3.01 (1.10)	3.66 (1.29)	*t*=27.22[3]
	Mode		2	3	
		N	5044	4959	
Child age	Average (SD)		9.04 (2.00)	8.66 (1.98)	*t* =-9.59[3]
	Mode		11	6	
		N	5044	4959	
[1] p<.0.5, [2] p<.0.1, [3] p<.00.1					

Table 3: Univariate analysis of proper restraint use for older children (6 to 12 years old)

were most likely to use CRS properly. Drivers with an invalid license (suspended due to driving violations or accidents) were less likely to restrain children properly than drivers with a valid license (OR=0.24). Unbelted drivers were less likely to restrain children properly than belted drivers (OR=0.35). Children were less likely to be restrained properly when the total number of occupants increased (OR=0.73), and with increasing age of the children (OR=0.69).

Variables		Adjusted OR	95% CI
Time of day	Day	1.00	
	Night	0.86	0.77-0.95[2]
Day of week	Weekdays	1.00	
	Weekends/bank/ holidays	1.01	0.92-1.10
Driver gender	Woman	1.00	
	Man	0.96	0.87-1.06
Driver age group	29 & under	1.00	
	30-39	1.19	1.08-1.31[3]
	40-49	1.09	0.92-1.29
	50-59	0.67	0.53-0.86[2]
	60 & older	0.70	0.52-0.96[1]
Driver licence	Valid	1.00	
	Not valid	0.24	0.06-0.91[1]
Purpose of travel	Commuting	1.00	
	Business	1.09	0.60-1.98
	Leisure	1.12	0.80-1.57
	Shopping	1.08	0.78-1.49
	Visit	1.10	0.79-1.54
	Escort	1.21	0.85-1.72
	Other private	1.22	0.87-1.69
Driver belt	Belted	1.00	
	Unbelted	0.35	0.24-0.52[3]
Number of occupants		0.73	0.70-0.76[3]
Child age		0.69	0.67-0.71[3]
[1] p<.0.5, [2] p<.0.01, [3] p<.001 Wald test			

Table 4: Adjusted odds ratios of proper restraint use for younger children (up to 5 years old)

Variables		Adjusted OR	95% CI
Day of week	Weekdays	1.00	
	Weekends/bank/ holidays	1.00	0.92-1.09
Driver gender	Woman	1.00	
	Man	1.02	0.93-1.13
Driver age group	29 & under	1.00	
	30-39	0.94	0.78-1.13
	40-49	0.97	0.80-1.78
	50-59	1.07	0.81-1.42
	60 & older	0.88	0.67-1.17
Type of car	Passenger car	1.00	
	Mini car < 660cc	0.93	0.85-1.02
Purpose of travel	Commuting	1.00	
	Business	1.48	0.75-2.91
	Leisure	1.04	0.68-1.58
	Shopping	1.09	0.72-1.63
	Visit	1.05	0.69-1.59
	Escort	0.96	0.63-1.47
	Other private	1.44	0.95-2.18
Driver belt	Belted	1.00	
	Unbelted	0.06	0.03-0.13[3]
Number of occupants		0.62	0.59-0.64[3]
Child age		1.09	1.07-1.1[3]
[1] p<.0.5, [2] p<.0.01, [3] p<.001 Wald test			

Table 5: Adjusted odds ratios of proper restraint use for older children (6 to 12 years old)

Table 5 shows the predictors of the proper use of restraints by older children when adjusted for independent variables. After conducting regression analysis using all nine independent variables as possible confounders (obtained from the results shown in Table 3), it was noted that the variable of child's seating position could well act as a synonymous variable with the outcome (r=-0.53). In other words, when children were seated in the rear seat, most were unrestrained. When children sat in the front passenger seat, they were mostly restrained. Therefore, the seating position variable was excluded from the regression model. Three variables were significant independent predictors. When drivers were unbelted, children were also likely to be unrestrained (OR=0.06). As the total number of occupants increased, children were less likely to be properly restrained (OR=0.62). With increasing age, children were more likely to be restrained (OR=1.09).

Conclusion

Summary of the results

- The present study investigated the behavioral and demographic characteristics of drivers and child passengers who were involved in not-at-fault rear-end collisions. It was apparent that restraint use patterns differed completely between children up to 5 years old (the target of the current law) and children 6 to 12 years old.

- Univariate analysis of younger children (up to 5 years old) showed that such children were less likely to be properly restrained when accidents occurred at night, on weekends, or on holidays, during leisure trips, when men or older people drove the car, drivers had an invalid license, drivers were unbelted, there were more occupants in the car, and when the children were older.

- Univariate analysis of older children (6 to 12 years old) showed that such children were less likely to be belted when accidents occurred on weekends or on holidays during leisure trips, when men and older people drove the car, children rode in passenger cars, drivers were unbelted, children were seated in the rear seat, there were more occupants in the car, and when the children were younger.

- When adjusted for confounders, six predictors of the proper use of restraints for younger children were identified. The following variables significantly decreased the odds ratio of proper restraint use: nighttime accidents, older (>50) drivers, drivers with an invalid license, unbelted drivers, more occupants in the car, and older children.
- When adjusted for confounders, three predictors of the proper use of restraints for older children were identified. The following variables significantly decreased the odds ratio of proper restraint use: unbelted drivers, more occupants in the car, and younger children.

Interpretation of the results

- For both younger and older children, the use of a safety belt by the driver, age of injured children, and total number of occupants are apparently the most powerful predictors of the proper use of restraints for children. The relationship between the use of a safety belt by the driver and use of restraints for children has already been established in previous studies (for example [4]). Although there are very few reportedly unbelted drivers who were involved in not-at-fault rear-end collisions, the use of child restraints did mirror the use of a safety belt by the driver. It was also indicated that drivers are only keen to properly restrain very young children. It is quite likely that instead of continuing to use a child seat or booster seat, many parents simply discard the seats before children outgrow the CRS. Therefore, older children – unless seated in the front, as is often the case when there are only two occupants in the car (the driver and a child) – are not restrained at all. When there are more than two occupants in the car, chances are that the children sit in the rear seat and are simply left unrestrained.
- It may well be that existing regulations, although unintentional, serve to accelerate a premature graduation from the CRS for children who are too small to be restrained by safety belts and instead are left completely unrestrained, which is facilitated by situations where most adult passengers in the rear seat do not wear safety belts. Therefore, the compulsory use of restraints by both adults and children should be introduced and promoted hand in hand.
- There seems to be certain tendencies observed among drivers who do not restrain younger children properly: older drivers, possibly grandparents, are clearly less likely to use CRS properly, indicating that this particular generation would need to be informed of existing regulations and why it is necessary to use the CRS. Secondly, drivers with an invalid license, usually due to multiple driving violations or at-fault accidents, were unlikely to restrain children properly. In contrast, such specific driver characteristics were not found among those who had older child passengers in the car.
- Given the generally low number of fatalities involving child passengers in car accidents (the percentage being 0.2% according to the original data set), it is extremely difficult to increase the perception among caregivers regarding the inherent risk of misusing CRS. Furthermore, many characteristics of child restraint use and motor vehicle travel tend to reduce the perception of such risk, such as motor vehicle travel and having child passengers being perceived as a controllable, common, non-catastrophic, and familiar risk. It may therefore be necessary to arouse a sense of outrage by appealing to people's fears in order to promote the perception of CRS misuse as a serious risk [5].
- Some limitations should be considered when interpreting the results. Child passengers who were not injured in car accidents are omitted from the NPA database, and the results may not be applicable to driver-child passenger groups involved in accidents other than not-at-fault rear-end collisions. Finally, the police-reported use of restraints is known to be inflated due to the false reporting by occupants seeking to avoid being ticketed for such violation, and this is more of a factor in accidents involving minor injury where the occupants typically exit their vehicles before the police arrive [5].

References

[1] National Police Agency: Japan Automobile Federation: Results of survey on restraint use. http://www.npa.go.jp/koutsuu/index.htm (accessed on May 31st 2006)

[2] P. BOASE, B.A. JONAH, N. DAWSON: Occupant restraint use in Canada. Journal of Safety Research, 35, pp. 223-229, 2004

[3] K. OKAMURA: Behavioral characteristics of drivers whose child occupants were injured or killed in the car (in Japanese). Gekkan Kotsu, 433, pp. 15-28, 2005

[4] T.R. MILLER, R.S. SPICER, D.C. LESTINA: Who is driving when unrestrained children and teenagers are hurt? Accident Analysis & Prevention, 30, pp. 839-849, 1998

[5] K.E. WILL, E.S. GELLER: Increasing the safety of children's vehicle travel: from effective risk communication to behavior change. Journal of Safety Research, 35, pp. 263-274, 2004

Poster Session:
Short Presentation

L. Hannawald

Y. Page, T. Hermitte

E. Tomasch, H. Steffan

R. de Lange, R. Happee, L. van Rooij, X.J. Liu

C. Klootwijk, R.H. Hoogvelt

D.A. Aylor, J.M. Nolan, D.S. Zuby, B.C. Baker

F. Kramer, W. Werner, J. Reimer

L. Hannawald
Accident Research Unit, University of Technology Dresden, Germany

Accident Research in Germany – Experiences of an Interdisciplinary Project

Abstract

The accident research project in Dresden was founded in July 1999. To date over 6.000 crash investigations have been undertaken. About 10.000 vehicles have been documented and over 13.000 participants have been debriefed. But there is much more than this scientific success.

Because of the interdisciplinary character between the medical and technical focus, the project affords an important contribution for the education of the involved students. Over 200 students of different fields of study have got experiences not only for the occupational career.

This lecture describes the additional effects of the accident research project regarding the education of the students, the capacity for teamwork and learning about dealing with accident casualties.

Form of Organization

The Accident Research Unit at the University of Technology Dresden is part of the GIDAS project, established by the German Automotive Industry Research Association (FAT) and the Federal Road Research Institute (BASt). Approximately 1 million inhabitants live in this area of about 3.000km^2

Work Scope

During the shift the team consists of two technicians, one medical student and one coordinator. Especially at the accident side the teamwork is of high priority. The team is especially provided with different cameras and measuring instruments for documentation, photogrametry and measuring purposes.

Furthermore the following data are collected:

- environmental conditions,
- particular construction features of the vehicles involved,
- design of the roads,
- traffic control.

The vehicles involved in the traffic accident are carefully investigated regarding:

- vehicle deformation,
- points of passengers' impact or off-road users outside the vehicle,
- technical identification data, vehicle type and equipment.

All persons involved are interviewed about:

- sequence of events during accident,
- persons' height and weight,
- driver's license with possible special conditions and other details.

Vehicles that cannot be investigated at the accident site are inspected the following day by another technical student.

The medical student drives to the scene of the traffic accident with an extra research vehicle. At the scene the medical employee supports the rescue units and starts the documentation of the injury patterns.

To complete this collection of data, information about the subsequent treatment of the injured in the hospital is added. The type, severity and location of all the injuries are documented.

Up to now more than 6.000 accidents are investigated by the accident research project in Dresden. Each accident side was measured and detailed drawing and extensive picture records were made. About 10.000 vehicles were inspected. More than 13.000 single collisions were detected and reconstructed. All in all about 20.000 single injuries were diagnosed by more than 7.500 injured participants in the last 7 years.

More than 3.000 single facts have to be coded by the students for each case. The complete duration for handling the data is about 25 hours per case.

These many facts indicate the high claim and interdisciplinary approach of the project. The correlation between technical and medical facts has a need for a complex teamwork at accident side and the later diagnosis and coding of the data.

Education of Students

About 50 students are employed continually for the documentation of accidents in the project who major either in automotive engineering or human medicine.

Since 1999 more than 220 students of different fields of studies get a special education at the project.

Every driver takes a great responsibility using the special right of way through the use of siren and flashing blue lights on the way to the accident site. Therefore all drivers of the research vehicles are trained on the legal background and the practical handling using the special right of way, on a quarterly basis. More than 25 of these trainings were implemented since 1999. In addition, a driving safety and handling training is offered in the same period of time.

Furthermore mainly the technical employees are instructed in providing advanced first aid.

They have to learn and train interview techniques, dealing with accident casualties and the understanding of technical, medical an road building aspects regarding the accident casuality.

Only extensive education of the technical students could provide such an intensive work. The same is obtained by medical students.

All students get an 2 months special education and single certification before they can work independently at the accident scene.

Additionally there were made over 50 seminar papers, diploma and master thesis in the last 7 years at the Accident Research Unit in Dresden.

Capacity for Teamwork

All students have learned to deal with injured participants up to fatalities at the accident scene. The ability to work in a team is the most important criteria for employment as a student in the research team. Further competences especially in psychological interview with the accident participants are important, too.

Further additional facts are the interdisciplinary effects for the students and the rational work mode they have learned. Most of the students talk about an individual learning process during the employment. Not less talk about a much more defensive individual characteristic of driving and personal maturity.

So the accident research project is more and more a secondary education for the employeers. The function is more than investigation of accidents.

Nevertheless the duration of employment is not longer than 2 years normally. After that time the students complete their study and make an application for employment in the free market mostly with very good chances of success.

Y. Page, Th. Hermitte
on behalf of the Trace Consortium
Laboratoire d'Accidentologie, de Biomécanique et d'études du Comportement Humain, Nanterre, France

The TRACE Project: An Initiative to Update Accident Causation Issues and Evaluate the Safety Benefits of Technologies

The Integrated Safety programme and the eSafety initiative stress that the development of Intelligent Transport Systems in vehicles or on roads (and especially in the safety field) must be preceded and accompanied by a scientific accident analysis encompassing two main issues:

- The identification and the assessment (in terms of lives saved and accidents avoided), among possible safety technologies, of the most promising solutions that can assist the driver or any other road users in a normal road situation or in an emergency situation or, as a last resort, mitigate the violence of crashes and protect vehicle occupants, pedestrians, and two-wheelers in case of a crash or a rollover.
- The determination and the continuous up-dating of the aetiology, i.e. causes, of road accidents (as well as the causes of injuries) and the assessment of whether the existing technologies or the technologies under current development address the real needs of road users infered from accident and driver behaviour analyses.

The general objective of the TRACE project (Traffic Accident Causation in Europe) is to provide the scientific community, the stakeholders, the suppliers, the vehicle industry and the other Integrated Safety program participants with a global overview of the road accident causation issues in Europe, and possibly overseas, based on the analysis of any and all current available databases which include accident, injury, insurance, medical and exposure data (including driver behavior in normal driving conditions). The idea is to identify, characterise and quantify the nature of risk factors, groups at risk, specific conflict driving situations and accident situations; and to estimate the safety benefits of a selection of technology-based safety functions. Expected outcomes are essentially reports.

Besides this, TRACE proposes three different research angles for the definition and the characterization of accident causation factors, TRACE proposes to improve the methods actually used in accident analysis (diagnosis and evaluation). And finally, TRACE intends to base the analyses on available, reliable and accessible existing and on-going databases (access to which will be greatly facilitated by a series of partners highly experienced in safety analysis, coming from 8 different countries and having access to different kinds of databases, in-depth or regional or national statistics in their own country, and for some of them in additional countries).

The project is to last 2 years and involves 16 full partners and 6 sub-contractors for a total of 386 man-months.

E. Tomasch, H. Steffan
Vehicle Safety Institute, Graz University of Technology, Graz, Austria

ZEDATU (Zentrale Datenbank tödlicher Unfälle in Österreich) A Central Database of Fatalities in Austria

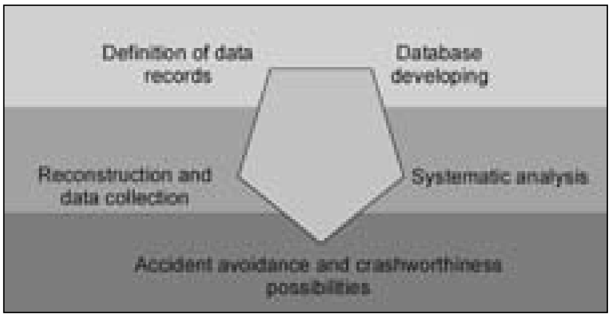


Figure 1: Project structure

Abstract

Due to recent years accident avoidance and crashworthiness on Austrian roads were mostly developed on national statistics and on-scene investigation respectively. Identification and elimination of black spots were main targets. In fact many fatal accidents do not occur on such black spots and black-spot investigation has reached a limit. New methods are required and therefore the Austrian Road Safety Programme was introduced by the Austrian Ministry of Transport, Innovation and Technology. The primary objective is the reduction of fatalities and severe injuries. Graz University of Technology initiated the project ZEDATU (Zentrale Datenbank tödlicher Unfälle) with the goal to identify similarities in different accident configurations. A matrix was established which categorizes risk and key factors of participating parties. Based on this information countermeasures were worked out.

Introduction

Besides of national statistics there is no database available allowing a (comparable) in-depth analysis. Even if the national database was enhanced for black-spot management driver's and pedestrian's behaviour can not be analysed. In-depth accident investigation which for instance includes vehicle performance in different crash scenarios only can be studied with a more comprehensive range of data fields.

National statistics can be seen as a base level with an assessment of accident situations and examination of trends. An intermediate level identifies hazardous road locations and in-depth accident investigation will take into account causation mechanisms or injury prevention measures, too. ZEDATU was initiated to examine road accidents on an in-depth basis and to identify similarities in different accident configurations which have overall validity. Many accidents are single vehicle accidents which do not take place at black spots but could have similar circumstances. Risk and key factors were developed to scrutinize causation conditions.

Project Structure

The project was divided into three levels with five Work Packages (Figure 1).

Definition of data records and developing of the database

The definition of the data records was based on the STAIRS (Standardisation of Accident and Injury Registration Systems) [1] protocol and enhanced by several different European projects, namely PENDANT (Pan-European Co-ordinated Accident and Injury Databases) [2], RISER (Roadside Infrastructure for Safer European Roads) [3] and ROLLOVER (Improvement of Rollover Safety for Passenger Vehicles) [4]. In addition data fields of national statistics were implemented into the database to ensure correlation with road accidents.

Accident risk and causation factors (Figure 2) were one of the basic parts during the project. Identification of the key factors was mainly found from police and expert technical reports, pictures from scene or witness reports and accident reconstruction respectively.

Reconstruction and analysis

Accident reconstruction was performed with PC Crash. The possibilities to avoid an accident of all participating parties were determined. Figure 3 shows an accident at a junction from the first

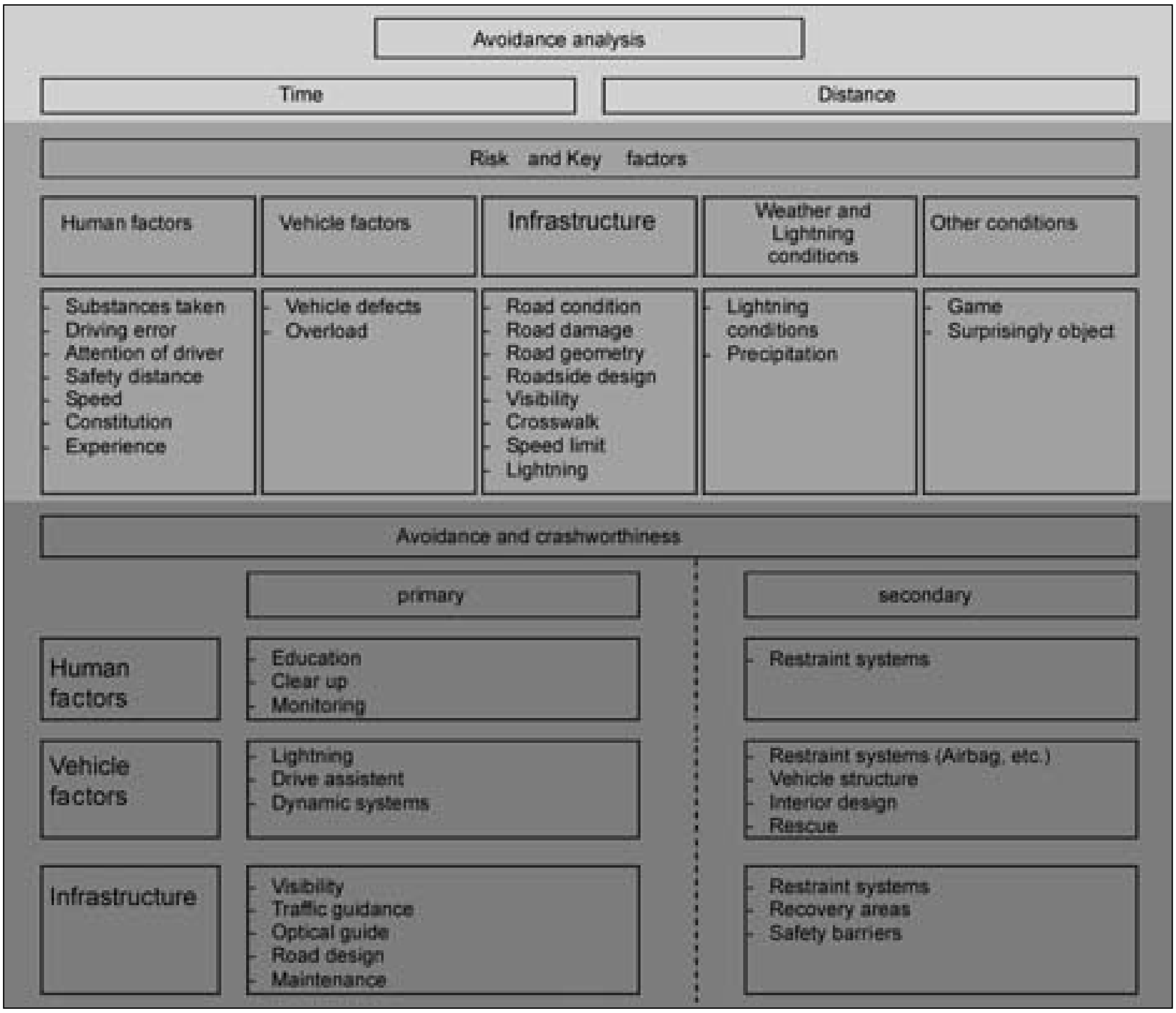


Figure 2: Matrix for accident analysis

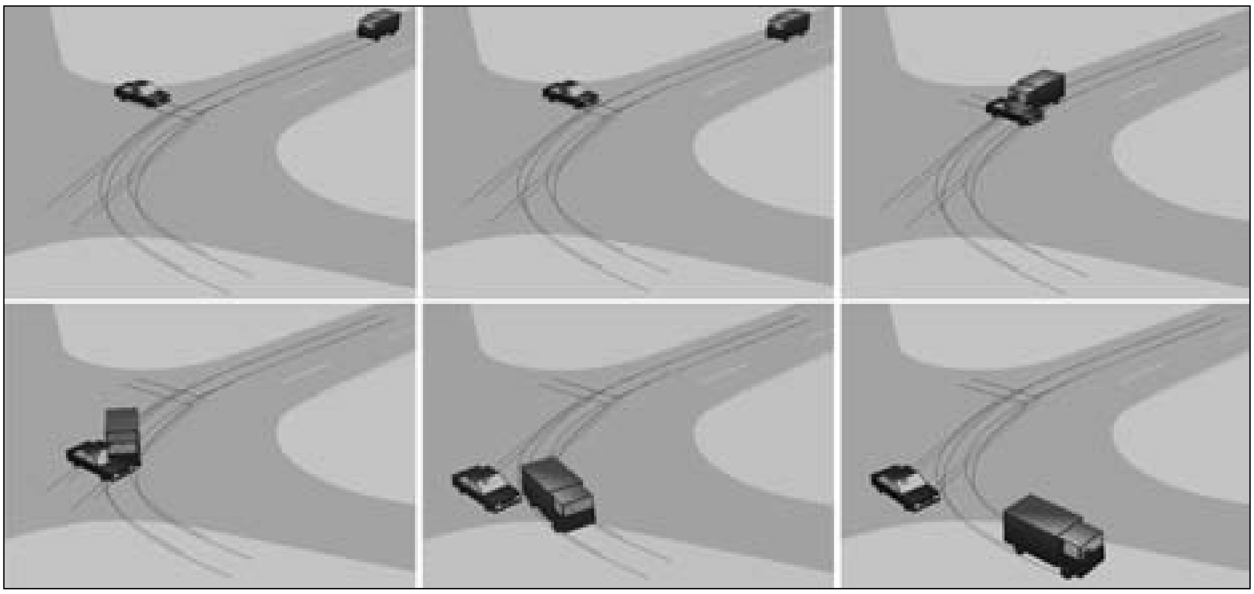


Figure 3: Accident sequences

movement of the smaller vehicle until the rest positions.

An analysis was made in a systematic manner. Firstly all Austrian accident types were studied and finally rollover and motorcycle accidents were analyzed separately. Within each accident type human factors such as use of seat-belt, age, gender etc. were comprised. Risk and key factors were investigated and analyzed for each accident type separately.

Accident avoidance and crashworthiness possibilities

Based on the analysis results a proposal has been worked out which included countermeasures for driver, vehicle and infrastructure. These countermeasures are based on primary or secondary safety. (Remark: Education and monitoring of seat-belt usage can be categorized as primary safety. Improvement of restraint systems or vehicle structure can be categorized as secondary safety.)

Results

A short summary of analysis provided that in single vehicle accidents only 40% of occupants were using the seat-belt for sure. Investigation of car accidents only show that close to 13% of analyzed fatal accidents resulted in a rollover. Additionally, rollovers mostly occurred in single vehicle accidents. 90% of the unbelted occupants were ejected during a rollover. Dangerous objects at the road side were identified as trees, poles or embankments (cut and fill slopes).

Discussion

Gathering the accident cases it was figured out that documentation of accidents varied in quality. Particularly pictures taken from scene and vehicles were inadequate. Only about 20% had good or perfect quality. For a huge number of single vehicle accidents documentation had poor quality, especially when only the driver was involved. The reason was found in Austrian's legislation. There is no law to punish self-injuries – hence little effort is taken by the police in investigating single car accidents thoroughly. Coding AIS (Abbreviated Injury Scale) was impossible for most of the fatal injured participants when no autopsy was made.

Conclusion

Currently no detailed in-depth fatality database is available in Austria nor in other European countries. ZEDATU has detailed information regarding human, vehicle and infrastructure. Due to the accident matrix it is possible to identify risk and key factors for each accident. STAIRS as the fundamental protocol should guarantee a harmonized data collection. ZEDATU based on STAIRS and enhanced by several European projects may provide accident data in high detail.

References

[1] http://www.lboro.ac.uk/research/esri/vsrc/stairs/index.htm

[2] http://www.vsi.tugraz.at/pendant/

[3] www.mvs.chalmers.se/~thomson/RISER/index.html

[4] http://www.vsi.tugraz.at/rollover/

R. de Lange, L. van Rooij
TNO Science and Industry, Automotive Safety, Delft, The Netherlands

R. Happee
TNO Automotive Safety Solutions, Delft, The Netherlands

X.J. Liu
TNO Automotive China, Shanghai, China

Validation of Human Pedestrian Models Using Laboratory Data as well as Accident Reconstruction

Abstract

Human pedestrian models have been developed and improved continually. This paper shows the latest stage in development and validation of the multibody pedestrian model released with MADYMO. The biofidelity of the multibody pedestrian model has been verified using a range of full pedestrian-vehicle impact tests with a large range in body sizes (16 male, 2 female, standing height 160-192cm, weight 53.5-90kg). The simulation results were objectively correlated to experimental data. Overall, the model predicted the measured response well. In particular the head impact locations were accurately predicted, indicated by global correlation scores over 90%. The correlation score for the bumper forces and accelerations of various body parts was lower (47-64%), which was largely attributed to the limited information available on the vehicle contact characteristics (stiffness, damping, deformation). Also, the effects of the large range in published leg fracture tolerances on the predicted risk to leg fracture by the pedestrian model were evaluated and compared with experimental results. The validated mid-size male model was scaled to a range of body sizes, including children and a female.

Typical applications for the pedestrian models are trend studies to evaluate vehicle front ends and accident reconstructions. Results obtained in several studies show that the pedestrian models match pedestrian throw distances and impact locations observed in real accidents. Larger sets of well documented cases can be used to further validate the models especially for specific populations as for instance children. In addition, these cases will be needed to evaluate the injury predictive capability of human models.

Ongoing developments include a so-called facet pedestrian model with a more accurate geometry description and a more humanlike spine and neck and a full FE model allowing more detailed injury analysis.

Introduction

Statistics show that pedestrian accidents are a major source of fatalities and injuries. In the European Union alone, about 6,250 pedestrians are killed every year in road accidents, while over 100,000 are severely injured (OTTE, 2001; EEVC, 1998). When the total amount of world-wide traffic fatalities estimated by MACKAY (2000) at 950,000 are combined with the World Bank (2003) statement that 65% of all traffic fatalities involve pedestrians, a yearly world-wide pedestrian traffic fatality number of 615,000 is estimated.

As the vehicle front is considered the cause for a significant amount of all pedestrian injuries, a considerable amount of effort has been put in recent years into designing strategies to reduce the aggressiveness of the vehicle exterior. In particular, changes in the design of the vehicle front and bonnet are considered to be effective, where both shape and stiffness of the vehicle are important parameters. Optimizing the vehicle front for pedestrian protection while maintaining the vehicle crashworthiness is a complicated and timely process. Mathematical simulations using biofidelic pedestrian models can help to efficiently assess the pedestrian protection in the early stages of the design process. In addition, mathematical modelling is a valuable tool to reconstruct pedestrian vehicle accidents as the models can provide insight into relevant crash parameters and into the kinematics of the pedestrian involved.

This paper describes the development and validation of the MADYMO human pedestrian models. In addition, typical applications and future developments are discussed using information from earlier studies done with the human pedestrian models. Special attention is paid to accident reconstruction to show the capabilities of the current models and to indicate how accident cases could improve the models validation.

Model Development and Validation

The pedestrian model (shown in Figure 1) presented in this paper has been created using multibody techniques available in the software package MADYMO. A first version of this model has been developed in a cooperation with Chalmers University as reported by de LANGE, HAPPEE, YANG and LIU (2001). A major update of the MADYMO pedestrian model has been published by HOOF et al. (2003) and the model is released with MADYMO 6.2.2. The outer surface of the model is represented by 64 ellipsoids and is based on the anthropometry data of an average Western European male obtained from the RAMSIS software (SEIDL, 1994).

The human-body pedestrian biomechanical data for the joints and segment parts were implemented from a variety of publications, together with detailed validation for the whole body as well as components. The majority of this data is concerned with the 50th percentile adult male model.

The contact characteristics for the various body regions were based on data found in literature and optimized in simulations of a large range of PMHS impactor tests on various body parts. The different impactor test configurations simulated are shown in Figure 2.

The validation results obtained with the pedestrian model are published by van HOOF et al. (2003). In general, the model approximates the measured PMHS response well, especially when the large range in test conditions and impacted body parts is considered.

A flexible leg model was implemented. Three spherical joints are specified in the upper leg dividing the upper leg (femur) into four equal parts. For the lower leg, also three joints are specified. For the required bending stiffness, a rotational force model was implemented. Angular stiffness functions were derived from simulations of quasi static bending tests done by YAMADA (1970).

In car-pedestrian collisions often fracture of the leg occurs. Therefore leg fracture is implemented in the human pedestrian model. Fracture joints were sited at the middle femur joint and at each of the tibia bending joints. The 50th percentile fracture levels were derived from literature.

Model validation has been made on both the body segments and on whole body simulations. For the verification of the lower extremity, the lower extremity model was separated from the full body pedestrian model. Impact tests with real human lower extremity specimens (KAJZER et al. 1990 and 1993) were simulated. In addition, three different sets of PMHS pedestrian-vehicle impact tests have been simulated to verify the biofidelity of the pedestrian model. Since PMHS subjects of different anthropometries were used in the tests, the pedestrian model was scaled to the specific body dimensions of each PMHS subject prior to simulating the corresponding test. In total 18 subjects (16 male, 2 female) were used in these tests, ranging in height from 160-192cm and in weight from 53-90kg. The results of the simulations were objectively compared with available experimental data. An extended description of the validation simulations and results can be found in van HOOF et al. (2003). From the extended validation of the pedestrian models it can be concluded that:

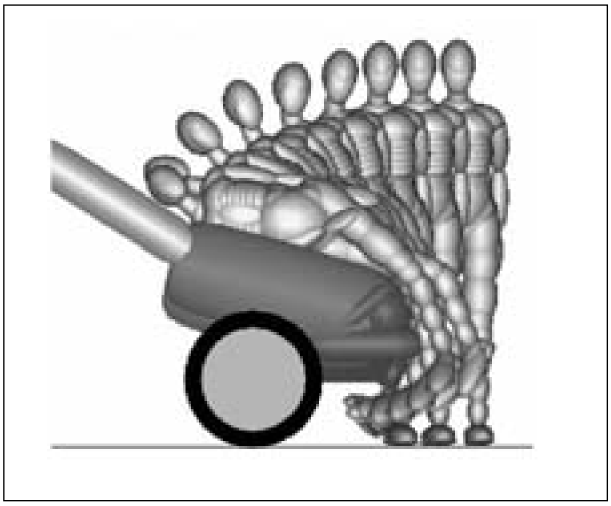


Figure 1: The MADYMO mid-size male pedestrian model

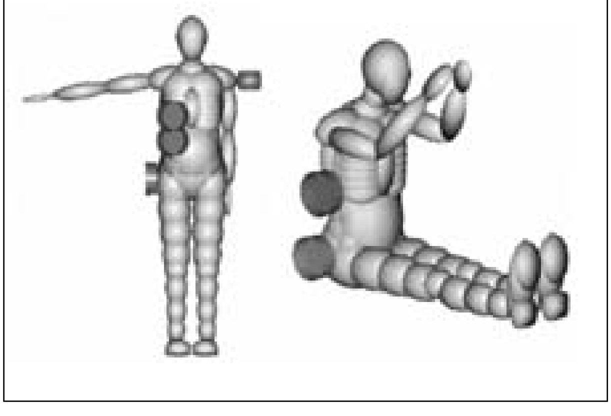


Figure 2: Range of impactor test configurations used for model validation

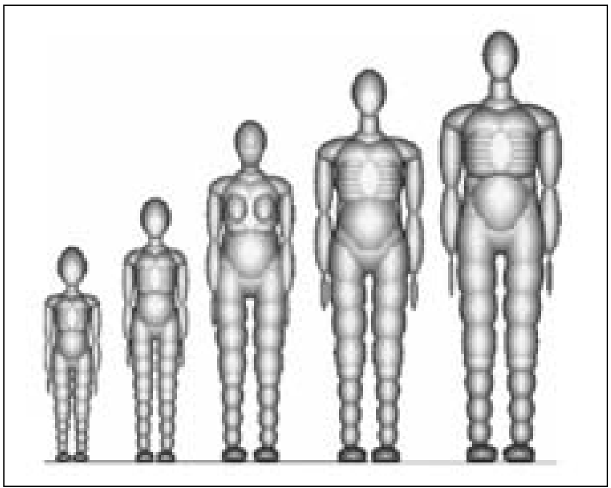


Figure 3: From left to right: models of 3 and a 6 year old child, small female, mid-size male and large male

	3 yr. old child	6 yr. old child	Small female	Mid-size male	Large male
Standing height [m]	0.95	1.17	1.53	1.74	1.91
Seated height [m]	0.55	0.64	0.81	0.92	1.00
Shoulder width [m]	0.25	0.28	0.40	0.47	0.52
Knee height [m]	0.28	0.35	0.47	0.54	0.59
Weight [kg]	14.5	23.0	49.8	75.7	101.1

Table 1: Anthropometry parameters of different body sizes

- the models accurately predict the global kinematics;
- the models accurately predict the impact points on the vehicle, especially for the head;
- the models can reasonably predict the occurrence of fractures in the upper and lower legs during the impact between the pedestrian and the vehicle;
- the models can predict the signal shape and trends of the head, chest and pelvis accelerations and the bumper forces.

The validated average male model was scaled towards a 3 year old child, 6 year old child, small female, and large male model (see Figure 3). The anthropometries of the small female and large male pedestrian models were also based on the RAMSIS database. The anthropometries of the 3 and 6 year old child were based on the specification of the Q child dummies. The global anthropometry specifications are given in Table 1.

The scaling of the pedestrian models was performed using the MADYMO/Scaler module (HAPPEE et al., 1998). Different scaling factors were specified for x-, y-, and z-dimensions and for different body parts to adapt the model geometry to the desired anthropometry. In addition to the geometry other model parameters were scaled.

As the pedestrian models are based on rigid body techniques the main advantages of this kind of models are the low computational costs, robustness and accurate predictions of kinematics. Therefore the model can be applied in studies involving a large number of runs, like stochastic simulations, for instance to determine ranges of impact conditions (e.g. head impact speed, head impact angle) for subsystem tests.

Typical Model Applications

A typical application is the evaluation of the pedestrian protection of the car front as for instance was done by HAPPEE and WISMANS (1999). HAPPEE and WISMANS first modelled and evaluated a production vehicle in MADYMO. Modifications were introduced such that all injury values were below 80% of the applicable tolerance values according to the EEVC test procedures (EEVC, 1998). Based on this optimised vehicle model, various vehicle models with markedly differing shapes were developed. As a next step, the 50th percentile male, a 5th percentile female and 3 and 6 year old child pedestrian models were applied to simulate lateral impact with the different vehicle models. From the simulations trends in injury reduction over the different vehicle models and over the various body sizes were identified.

As the pedestrian model can be scaled towards any desired body size, accident reconstruction is another typical application. Already a number of studies exist where the MADYMO pedestrian models are used in accident reconstruction simulations. COLEY et al. (2001) used an earlier version of the pedestrian model to reconstruct a real-world accident with a scaled version of the 5th percentile female pedestrian model. The performance of the pedestrian model was evaluated and afterwards the model was applied to reconstruct a fatal accident using a detailed vehicle model. Firstly the impact points between the pedestrian and the vehicle were matched and secondly the injury pattern was assessed by relating the injury value to an AIS level. In addition, further impact scenarios were explored to assess the ‘injury variation’ based on vehicle stiffness, initial pedestrian posture and position.

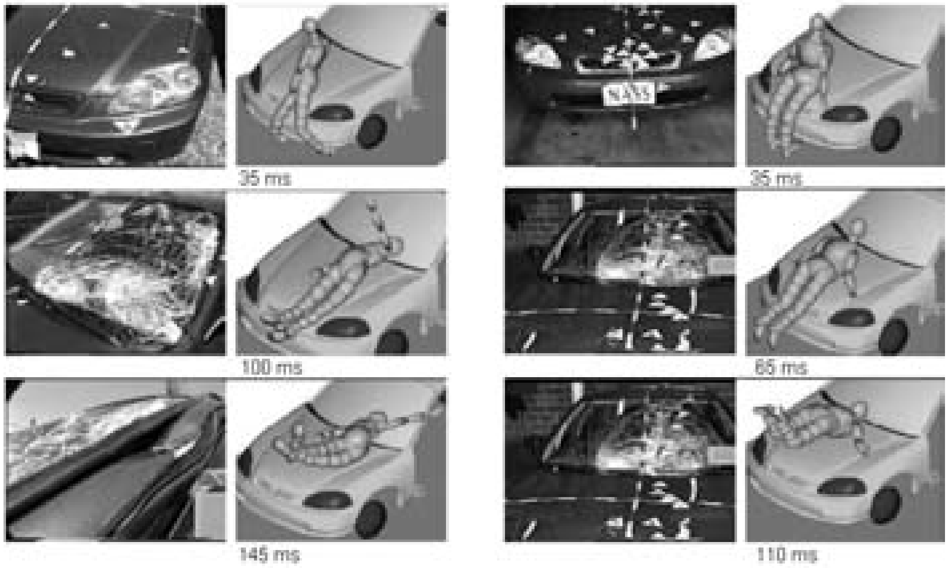


Figure 4: Comparison of the marks on the case vehicles with the contact locations in the MADYMO simulations (source: van ROOIJ et al., 2003)

In GLATIN et al. (2002) the focus was more on the throw distance of the pedestrian. In his study, GLATIN found an accurate match of throw distances between the simulations and the real-world data.

In 2004 STRZELETZ et al. compared the accident reconstruction simulations with the pedestrian models in MADYMO with several other numerical and experimental methods to further analyse pedestrian accidents. In his study STRZELETZ concluded that the accident reconstruction simulations in MADYMO do provide valuable information on the pedestrian model kinematics and the impact locations on the vehicle. As most parameters relevant in the accident are defined explicitly, the simulations were well suited to study the influence of differences in the initial conditions and the importance of different input parameters.

Van ROOIJ et al. (2003) developed and validated a vehicle model of a small family car using subsystems. He applied the developed vehicle model together with pedestrian models to reconstruct two pedestrian accident cases from the PCDS database (CHIDESTER et al., 2001). Case 1 was a non-fatal accident where a male (standing height: 1.75m; body weight: 79kg) was impacted with about 69km/h. Case 2 was a fatal accident where a female (standing height: 1.65m; body weight: 105kg) was impacted with 55km/h. A braking of 0.7G was applied to the vehicle model based on tire marks. The pedestrian models were scaled towards the required anthropometry using the MADYMO/Scaler module. A variation study was performed with a number of parameters like vehicle velocity, initial position and posture of the pedestrian model. Contact points between the pedestrian and the vehicle were compared with the marks on the accident vehicle. Based on this comparison (see Figure 4), the most likely accident scenario was derived.

For the two most likely scenarios, the injury outcome from the accidents was compared with the injury predictors in the models. In case 1, the leg injury results matched the observed severe leg injury and for case 2, the neck loads (N_{ij}) matched the fatal atlanto-occipital fracture observed in the accident.

Currently the MADYMO pedestrian models are used in the EC project APROSYS, to reconstruct pedestrian-vehicle and cyclist-vehicle accidents. The main aim of these reconstructions is to determine the impacted areas of the vehicle and to determine the nature of the loading conditions on the body of the pedestrian and pedal cyclists, including the head.

Ongoing Model Developments

The pedestrian models presented in this paper are based on the rigid body techniques available in MADYMO. As mentioned, the main advantages of this kind of models are the low computational costs,

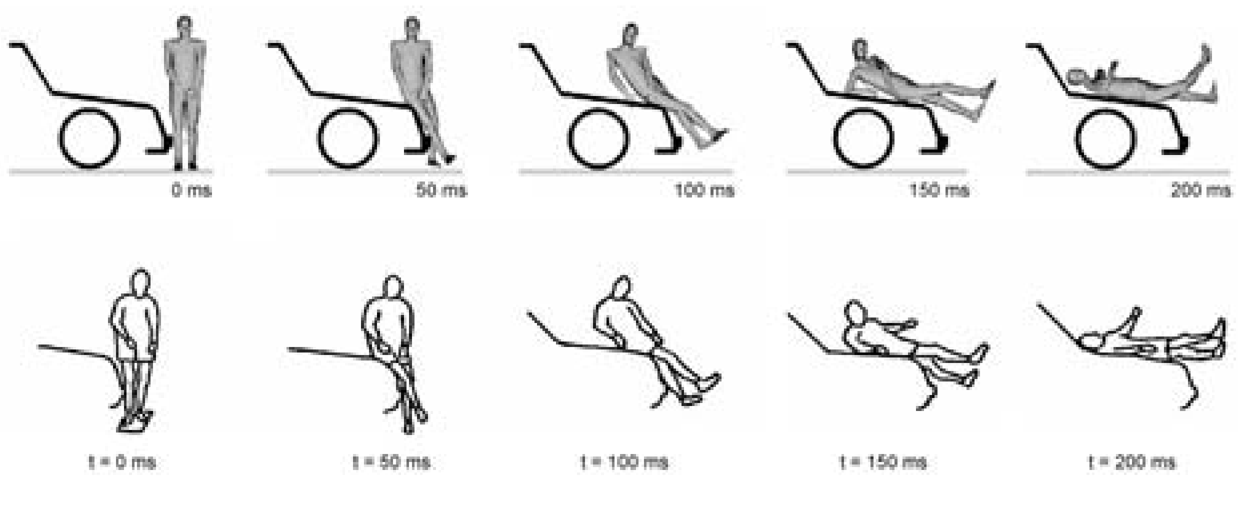


Figure 5: The kinematics of the facet pedestrian model in a 25 km/h impact and the corresponding test result as published by ISHIKAWA (1993)

robustness and accurate predictions of kinematics. Since ellipsoids were used to represent the geometry of human and vehicle, the prediction of the contact interaction is largely simplified.

A more advanced modelling technique is used for the MADYMO facet human model which can be seen in Figure 5. In this model the articulations are modelled with rigid body techniques and the skin with an so-called arbitrary surface. The model contains a more realistic spine and neck and a more detailed geometrical representation of the human body, but has limited capabilities to predict deformations. The model has been developed and validated for occupant impact simulations (LANGE et al., 2005). Due to its biofidelic set-up and the more accurate geometry description compared to the ellipsoid pedestrian models, this model is currently evaluated for its suitability for pedestrian impact simulation. As a first validation, several pedestrian tests published by ISHIKAWA et al. (1993) have been simulated. Figure 5 shows the kinematics of the average male pedestrian model in a 25km/h impact and the corresponding test result. As can be seen, the pedestrian kinematics correspond well with the pedestrian kinematics obtained in the test and also the impact locations between the pedestrian and the vehicle correspond well.

Additionally, the finite element (FE) technique enables prediction of detailed contact interactions and resulting deformations in structures with complex geometries. Recently, the FE human model developed in the EC project HUMOS 2 was adapted to a standing model and evaluated for lateral pedestrian impact (VEZIN and VERRIEST, 2005). Such a FE model enables more detailed analyses of the injury biomechanics associated with pedestrian impacts, such as bending and fracture of the bones and rupture of the ligaments. However, the main disadvantage of the FE approach is the much higher computational cost compared to rigid body. Furthermore critical stability issues are observed in soft tissue compression, which as yet prohibit routinely usage of such full FE human models.

One way to circumvent these limitations is to combine rigid body and FE techniques in one model. In this way an optimal combination of computational speed and accuracy can be obtained. A valuable combination could for instance be a rigid body pedestrian model combined with a FE model of the impacted leg. Such a model could provide a detailed insight in the leg injuries obtained, and as the remainder of the body is modelled with rigid body techniques, the computation time is still acceptable.

Discussion

As shown in this paper, the developed pedestrian models are used in a number of studies to reconstruct pedestrian-vehicle accidents. From these accident reconstruction studies it was concluded that throw distances of the pedestrian and, similar to the results of the validation, impact locations on the vehicle match fairly accurate with the experimental results and reconstructed accidents. This indicates a correct kinematic response of the pedestrian models. As such, accident reconstruction simulations help to obtain more details on specific accident cases and to provide an increased understanding of the sequence of events in the car-pedestrian impact. From the validation study it was concluded that the pedestrian models can reasonably predict the occurrence of fractures in the legs during the impact and that the models can predict trends in other injury parameters. This is supported by the findings of van ROOIJ et al. (2003), but more accident reconstructions of well documented cases are needed to further evaluate the predictive injury capability of human models, such as in LONGHITANO et al. (2005).

If a large number of accidents is reconstructed using similar methods as described above, such studies could lead to an improved validation of the human pedestrian models. This is thought to be valuable especially for specific populations as children and elderly pedestrians, where body tissue and bone fracture properties vary significantly from the 50th percentile due to the age effects. For children, where neither body properties nor tolerance values are known, scaled human-body models can be used as a start and further modified based on the known differences between children, mid-aged adults and elderly people. As a first step in this method, LIU developed child pedestrian models and used the models to reconstruct two real world accidents using the accident data from in-dept accident investigations (LIU and YANG, 2002). In this study, it was concluded that the overall trajectories of the child models and vehicles and the head impact locations did correspond well with the accident data and the results indicated an acceptable correlation with the real-world injuries.

Besides the availability of a large number of accidents cases, such accident reconstruction studies for validation can only be performed if the cases are well documented and the reconstruction simulations are performed with a vehicle model that accurately matches the detailed geometry and the stiffness. Both parameters will have a significant influence on the model's response. Also the anthropometry of the pedestrian involved in the crash has a significant influence on the pedestrian kinematics in a pedestrian-vehicle impact. Therefore, the anthropometry has to be matched accurately by the pedestrian model which can be obtained using the MADYMO/Scaler module.

Conclusion

The MADYMO human pedestrian models have been verified using a range of full pedestrian-vehicle impact tests with a large range in body sizes. The models are available in number of body sizes ranging from a 3 year old child to a large male. In addition a scalable version has been developed.

The models are suitable as a tool for the reconstruction of pedestrian-vehicle accidents. The accident reconstruction studies described in this paper have shown that the simulations with the pedestrian models provide an improved understanding of the reconstructed accidents. Pedestrian kinematics, impact locations and pedestrian throw distances resulting from the simulations can be matched accurately with the accident observations. Provided that a large number of well documented pedestrian accidents could be reconstructed, this can even lead to an improved validation of the pedestrian models. This is thought to be especially valuable for specific population groups like children were currently sufficient data for validation is lacking.

Ongoing developments include a so-called facet pedestrian model with a more accurate geometry description and a more humanlike spine and neck and a full FE model allowing more detailed injury analysis.

Acknowledgements

The authors want to acknowledge J.B. REGNIER for his contribution to the validation of the facet pedestrian model. In addition, as information from a number of studies is used, the authors would like to thank the authors of those publications for sharing their information.

References

G. COLEY, R. LANGE, P. de OLIVEIRA, C. de NEAL-STURGESS, R HAPPEE: Pedestrian Human Body Validation Using Detailed Real-World Accidents, Proceedings of the IRCOBI Conference, 2001

A. CHIDESTER, R. ISENBERG: Final Report – The Pedestrian Crash Data Study, Proceedings of the 17th International Conference on the Enhanced Safety of Vehicles, Amsterdam, The Netherlands, 2001

European Enhanced Vehicle Safety Committee (EEVC): Working Group 17 report – Improved test methods to evaluate pedestrian protection afforded by passenger cars, 1998

N.N. GLATIN, M. LE, G. BLUNDELL, B. BROWN, B. ALLAN-STUBBS: Results of a Design of Experiments simulation of real world pedestrian vehicle accidents, Presented at the 9th international MADYMO user conference, Como, 2002

R. HAPPEE, R. HAASTER, L. van ROOIJ, L. MICHAELSEN, R. HOFFMANN: Optimisation of vehicle passive safety for occupants with varying anthropometry, Proceedings of the 16th International Conference on the Enhanced Safety of Vehicles, Canada, 1998

R. HAPPEE, J. WISMANS: Pedestrian protection full-body simulations, dummy validation, Proceedings of the VDA Technical Congress, Frankfurt, 1999

J. van HOOF, R. de LANGE, J. WISMANS: Improving Pedestrian Safety Using Numerical Human Models, Proceedings of the 47th Stapp Car Crash Conference, 2003

H. ISHIKAWA, J. KAJZER, G. SCHROEDER: Computer Simulation of Impact Response of the Human Body in Car-Pedestrian Accidents, Proceedings of the 37th Stapp Car Crash Conference, 1993

J. KAJZER, C. CAVALLERO, S. GHANOUCHI, J. BONNOIT, A. GHORBEL: Response of the Knee Joint in Lateral Impact: Effect of Shearing Loads, Proceedings of the IRCOBI Conference (pp. 293-304), 1990

K. KAJZER, C. CAVALLERO, J. BONNOIT, A. MORJANE, S. GHANOUCHI: Response of the Knee Joint in Lateral Impact: Effect of Bending Moment, Proceedings of the IRCOBI Conference (pp. 105-116), 1993

R. de LANGE, R. HAPPEE, J.K. YANG, X. LIU: Development and validation of full body human pedestrian models, TNO Automotive, The Netherlands, 2001

R. de LANGE, L. van ROOIJ, J. WISMANS: Objective Evaluation of a Human Model for Frontal to Lateral Impact, Proceedings of the 49th Stapp Car Crash Conference, 2005

X.J. LIU, J.K. YANG: Development of Child Pedestrian Mathematical Models and Evaluation with Accident Reconstruction, Journal of Traffic Injury Prevention, Volume 3 (pp. 321-329), 2002

D. LONGHITANO, C. BURKE, J. BEAN, D. WATTS, S. FAKHRY, M. MEISSNER, J. IVARSSON, C. SHERWOOD, J. CRANDALL, Y. TAKAHASHI, Y. KADOTANI, R. HITCHCOCK, Y. KINOSHITA: Application of the CIREN methodology of the study of pedestrian crash injuries, Proceedings of the 19th International Conference on the Enhanced Safety of Vehicles, Washington, U.S.A., 2005

M. MacKAY: Folklore and Science in Traffic Safety: Some New Directions, Injury Prevention and Control, London, Taylor & Francis, (pp. 89-98), 2000

D. OTTE, T. POHLEMANN: Analysis and Load Assessment of Secondary Impact to Adult Pedestrians after Car Collisions on Roads, Proceedings of the 17th International Conference on the Enhanced Safety of Vehicles, 2001

A. SEIDL: Das Menschmodel RAMSIS: Analyse, Synthese und Simulation dreidimensionaler Körperhaltungen des Menschen, PhD dissertation, Technical University of Munich, Germany, 1994

R. STRZELETZ, K. KÜHN, A. KAMPA: Vergleichende Bewertung von Simulation und Experiment am Beispiel des Fußgänger-Fahrzeug-Unfalls, EVU Conference, Prague, 2004

L. van ROOIJ, K. BHALLA, M. MEISSNER, J. IVARSSON, J. CRANDALL, D. LONGHITANO, Y. TAKAHASHI, Y. DOKKO, Y. KIKUCHI: Pedestrian crash reconstruction using multi-body modeling with geometrically detailed, validated vehicle models and advanced pedestrian injury criteria, Proceedings of the 18th International Conference on the Enhanced Safety of Vehicles, 2003

P. VEZIN, J.P. VERRIEST: Development of a set of numerical human models for safety, Proceedings of the 19th International

Conference on the Enhanced Safety of Vehicles, Washington, U.S.A., 2005

World Bank Group Road Safety: http://www.worldbank.org/html/fpd/transport/roads/safety.htm (accessed February 20th, 2003), 2003

H. YAMADA: Strength of biological materials, Baltimore, Maryland Williams and Wilkins, 1973

C.W. Klootwijk, R.H. Hoogvelt
TNO Science and Industry dept. Automotive, Safety, Delft, The Netherlands

Sensitivity of Car with Guardrail Impacts with a Multibody Simulation Tool

Abstract

The European Union has set a target to reduce all road fatalities (over 40,000) with 50% in 2010. This target percentage remained unchanged with the introduction of the ten new member states within the EU as by May 1st, 2004. According to Eurostat [1], 34% of all fatalities in 1998 in the, then, fifteen states of the European Union were the result of single vehicle collisions. This represents over 14,000 lives lost each year of which many can likely be saved through better roadside infrastructure design. The challenge for road safety professionals is to find methods and design strategies that help to reduce these casualties.

Procedures for full-scale vehicle crash testing of guard rails were first published in the US in 1962. Present European regulation is mainly based on these procedures and later developments. Since then the vehicle fleet has changed considerably. Due to the complexity of the actual safety problem the numerical simulation approach offers a good opportunity to evaluate the different parameters involved in road safety, such as infrastructure properties, vehicle type, vehicle occupants and injuries. The ideal situation would be that simulation tools are coupled or integrated and all involved effects would be related. At the moment this is not the case yet, but initiatives are taken and a new virtual era has started.

This paper offers a method looking at two components that encompass the driving environment: the car and the guardrail.

As part of the EC-funded project, RISER (Roadside Infrastructure for Safer European Roads) a multi body simulation program study is carried out to determine sensitivities of some parameters in car to guardrail collisions and gives insides in performance of the car with passive safety equipment, the guardrail and the interaction of these objects with each other.

By offering a set of methods that includes these two aspects and their intertwining relations, more confidence can be gained in actually reducing fatalities due to single vehicle collisions with, or due to, roadside furniture. Reducing the number of fatalities of single vehicle crashes would contribute greatly to the stated goal of reducing casualties altogether.

Introduction

In the RISER project different simulation techniques were used. The simulations give insights in the infrastructure-vehicle interaction and the vehicle-occupant interaction. The used simulation tools are the multibody program MADYMO with ADVISER. Details about the work carried out have been reported in the deliverable D03 Critical vehicle and infrastructure interactions [3].

MADYMO (Mathematical Dynamic Model) is a computer program that simulates the dynamic behavior of physical systems especially those emphasizing the analysis of vehicle collisions and assessing injuries sustained by passengers. MADYMO is a combined multibody-finite-element code.

ADVISER is a tool that manages stochastic simulations and analysis, which provides insight in the effect of parameter variations on e.g. the injury criteria. The tool also automatically correlates numerical and experimental data and provides a corresponding objective quality rating for a numerical model.

Guardrail impacts

A countermeasure to avoid single run off accidents with passenger cars is to install guardrails. The guardrail is a device to change the direction of the passengercar. By changing the direction of the car a run off into the roadside is avoided. During and after redirecting the passenger car the guardrail will also slow down a vehicle, so energy is dissipated. Lower energy level results in lower crash speed and will therefore cause lower injuries.

For the RISER project a specific methodology was set up. First a car and a guardrail model were built up and then combined in a simulation. This simulation was the basis for a study with stochastic simulations.

With the software package ADVISER it is possible to perform stochastic simulations. ADVISER offers three sample approaches, of which Monte Carlo is the most basic and Best Latin Hypercube the most advanced. The concept is described in [1] and [2]. For each parameter in the numerical model, N samples can be generated according to a pre-defined distribution (uniform, Gaussian, etc.). The amount of samples is not pre-determined as with DoE but depends on the degree of certainty that is required by the researcher and is independent of the number of parameters varied. Each sample set of parameter values is used to run a deterministic simulation of the model. These N simulations can be run in arbitrary order, as all simulations are independent. This allows to efficiently distributing the sample over a large number of CPUs, thus being able to run even larger samples within a reasonable time frame. The result of this method is N solutions of the stochastic model. So, instead of a single deterministic result, there is a cloud of solutions, which provide a better understanding of the sensitivity of the model. The method is different from the standard parameter variation, where only one parameter at a time is varied. In stochastic simulation the user only defines a range by the minimum and maximum values for all parameters, which are then randomly distributed over the range for all simulations. The output measures can be analyzed for trends and correlations with statistical methods.

Parameters	Symbol	Unit	Min	Max
Impact speed	v	[m/s]	10	28
Impact angle	β	[°]	5	35
Vehicle orientation	φ	[°]	0	45

Table 1: Parameters and ranges of variation

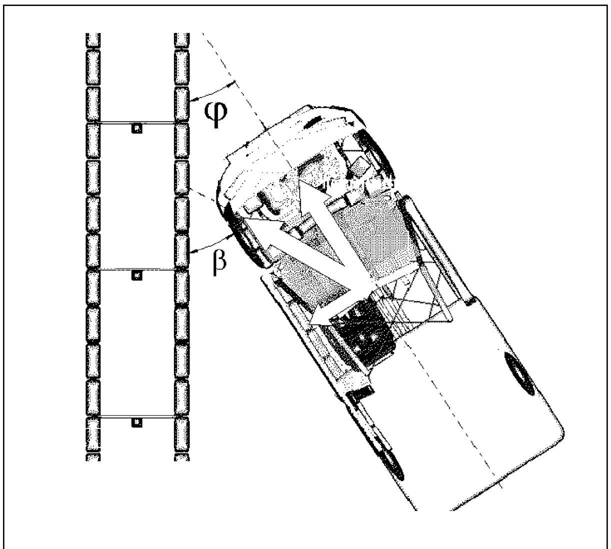


Figure 1: Definition of v, β and φ

The parameters are varied stochastically around those used in the test (impact speed 100km/h, impact angle 20°, vehicle orientation 20°). The aim of this parameter study is to determine sensitivity of certain parameters on the impact response and to investigate whether there is a relationship between the human-based HIC and the vehicle-based ASI.

Stochastic model set up

The impact speed, the velocity angle and the orientation of the vehicle are varied. The specific parameters including their minimum and maximum values are shown in Table 1.

In Figure 1 the vehicle and parameters are visualized. Samples of different parameter combinations are generated with the Best Latin Hypercube method, creating a random and uniform distribution that fills the whole parameter space. A total of 22 samples are generated. The trends and correlations are analyzed with linear regression analysis (LRA).

Results

It is expected that there is a positive correlation between ASI and the velocity. The trend shown between velocity and ASI gives confidence in the model sensitivity to changes in velocity. The scatter in the 22 tests is partially caused by the fact that besides variations in impact velocity also the impact direction and orientation of the vehicle were varied.

In the simulations also the HIC-values are calculated from the Hybrid III dummy model. A relationship between HIC and ASI exists as shown in Figure 3. Most of the test runs have ASI values below 2.00 and HIC values below the tolerance limit of 1000. The spread on the results is caused by the complexity of the three variables that are altered within this study; impact velocity, impact direction and vehicle orientation. The injury parameters taken into account in this study are HIC, VC and chest deflection and also the vehicle based criteria ASI, THIV and PHD. As shown in Figure 2 and Figure 3 a reasonable correlation between the varied parameters (such as velocity) and the responses (such as HIC and ASI) can be observed. Similar correlations exist for other injury parameters.

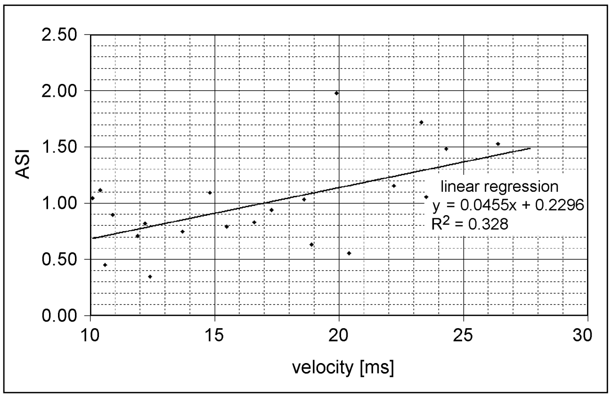


Figure 2: Relationship between velocity and ASI

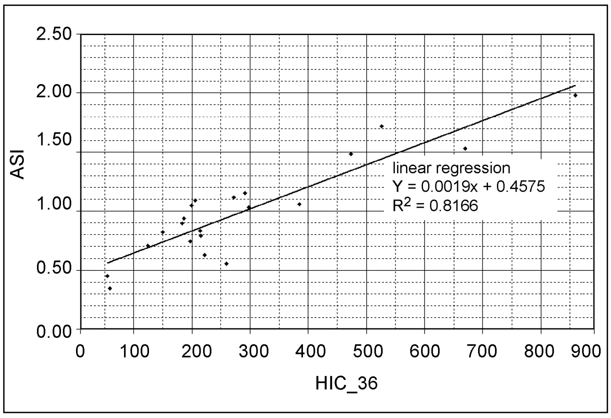


Figure 3: Linear correlation between HIC and ASI

Conclusions of the Stochastic Simulation

- The MADYMO model of the guard rail replicates reasonably the guard rail impact. The vehicle was successfully redirected. Future work however should be based on validating the response of the vehicle with respect to the guard rail. Also the guard rail model needs validation on component level in future studies.
- A stochastic approach provides insight into the system behavior on a multi-parameter and multi-scenario level. Stochastic simulations allow for the variation of both environmental parameters, such as impact speed and angle, as well as structural parameters, such as guard rail stiffness or vehicle mass. Generating a large sample of runs with multiple parameters does not result in perfect correlation due to a large spread of parameters in the stochastic models. However, it does result in trends between parameters, and further research is reasonable.
- The stochastic study showed that the model response, in terms of ASI, is sensitive to changes in impact velocity, as is expected for the defined combination 'vehicle and guard rail'. In addition, a relationship between ASI and HIC is shown for the simulated scenarios of impact speeds ranging from 35 to 100km/h at impact angles between 5° and 35°. The result indicates that ASI is a reasonable predictor of injury in guard rail impacts. This would justify certification of guard rail systems based on vehicle accelerations instead of dummy readings, hence saving the cost of using a dummy in regulatory tests.
- The relatively long duration of a vehicle-to-guardrail collision leads to long simulation times compared with a vehicle-to-vehicle collision simulation. This makes multibody approach very efficient with respect to finite element computer simulations.
- Extensive model validation is a pre-requisite for an absolute qualification of a guard rail system, however, a non-validated but realistic model provides insight in trend and sensitivity studies.

References

[1] ADVISER USER_S Guide; Version V1.4, MECALOG Business unit Safety; May 2004

[2] ADVISER Reference Guide; Version V1.4, MECALOG Business unit Safety; May 2004

[3] Critical vehicle and infrastructure interactions, RISER, February 2006

D.A. Aylor, J.M. Nolan, D.S. Zuby, B.C. Baker
Insurance Institute for Highway Safety, Arlington, USA

How the 64.4km/h (40mi/h) Frontal Offset Deformable Barrier Crash Test Relates to Real-World Crash Severity

Abstract

This study updates previous IIHS studies comparing estimated delta Vs for crash tested vehicles to the distribution of estimated delta Vs in the National Automotive Sampling System (NASS) Crashworthiness Data System (CDS). The delta V estimates for 232 frontal crash tests at 64.4km/h into a deformable barrier with 40 percent overlap are compared with estimates from frontal offset crashes in the 1997-2004 NASS database. All delta V estimates were based on SMASH, the delta V estimating program used by NASS since 1997. Results indicated that for all vehicles tested by IIHS, SMASH delta Vs were, on average, 32 percent lower than impact speeds and about 28 percent lower than the expected delta V. Almost 80 percent of all real-world frontal crashes resulting in AIS 3+ injuries and just over 60 percent of all fatal crashes occur at or below the average estimated delta V calculated for crash tested vehicles.

Introduction

Since 1995 IIHS has conducted frontal offset deformable barrier crashworthiness tests as part of a consumer information program. In the offset test, 40 percent of the vehicle's width strikes a deformable barrier at 64.4km/h [1]. The effectiveness of consumer testing depends on the test configuration and speed being relevant to real crash situations and on the test producing a range of test results. Frontal offset crashes make up a significant number of real-world crashes that result in serious injuries to the occupants [2], and the 64.4km/h-test speed initially produced a range of test results [3]. Previous studies showed that this test speed produced a crash severity below which a majority of real-world crashes involving serious injury occurred [4, 5]; thus vehicle changes made in response to these consumer ratings could be expected to reduce injury risk in similar real crashes. The present study updates the previous studies relating real-world severity with the severity of vehicle crash tests by providing results from an additional 175 crash tests of 1998-2005 model year cars, minivans, pickups, and SUVs and using more recent NASS data [6].

Real-Word Crash Severity

Crash severity is frequently gauged by delta V, which is the velocity change that occurs during the crash impact and which can be related to crash forces if the time over which the delta V occurs is assumed to be similarly small for all crashes. Delta V is calculated using the principles of conservation of energy and momentum plus an estimate of the energy absorbed in crushing the vehicle structure, which is based on measurements of the crashed vehicle and estimates of its structural stiffness. Because it only accounts for velocity change associated with vehicle crushing and does not include structural restitution or post-impact kinematics, delta V generally is not an estimate of the speed just prior to impact. Despite being only a rough estimate of the accelerations and forces involved in a crash, delta V is a useful measure because it is available for many crashes in NASS. The same measure can be applied for vehicles subjected to crash tests under known conditions.

The delta V for frontal offset crashes against a fixed barrier, like the tests that are the subject of this analysis, will be lower than the impact speed because the vehicle's center of mass does not stop at maximum crush. However, the forward velocity due to vehicle rotation and vehicle rebound is relatively small. The 1998 study used high-speed film to analyze the rotation of vehicles in the offset test and found that the energy associated with rotation accounted for 2 to 3km/h [2].

Methods

This analysis includes delta V estimates for 232 frontal offset crash tests, which include 134 passenger cars, 64 SUV, 22 minivans, and 12 pickup trucks. Each tested vehicle's front crush was measured according to the protocol established for crash reconstructions using the SMASH algorithm that has been used in NASS since 1997. The vehicle stiffness values for each reconstruction were assigned according to the same size/stiffness categories used by NASS investigators. The crash test delta Vs were compared with frontal offset crashes in the 1997-2004 NASS CDS database. Crashes were selected based on the Collision Deformation Classification, which includes principal direction of force, impact location, and amount of direct engagement. All single- and two-vehicle towaway crashes coded as frontal (19,648 cases), with one-third to two-thirds direct damage to the front-end and 11 to 1 o'clock principal direction of force (9,001 cases), were initially included, but comparable delta V estimates were only available for about half (4,487) of these cases.

Results

The SMASH delta Vs were not only lower than the 64.4km/h crash test speed but also lower than the test vehicles' expected delta Vs when an estimate of vehicle rotation is taken into account. The average SMASH delta Vs was 36 percent lower than the impact speed for cars, 21 percent lower for minivans, 31 percent lower for SUVs, and 9 percent lower for pickup trucks. The average SMASH delta V for all vehicles was 44km/h, or 32 percent lower than the impact speed. Taking into account the velocity associated with vehicle rotation found in the previous study, the SMASH delta Vs are approximately 28 percent lower than the actual delta Vs. Not only did SMASH underestimate delta V but there was considerable variation in the estimates for these 232 vehicles, all of which were subjected to the same crash test. Figure 1 shows the distribution of SMASH delta V estimates by vehicle type.

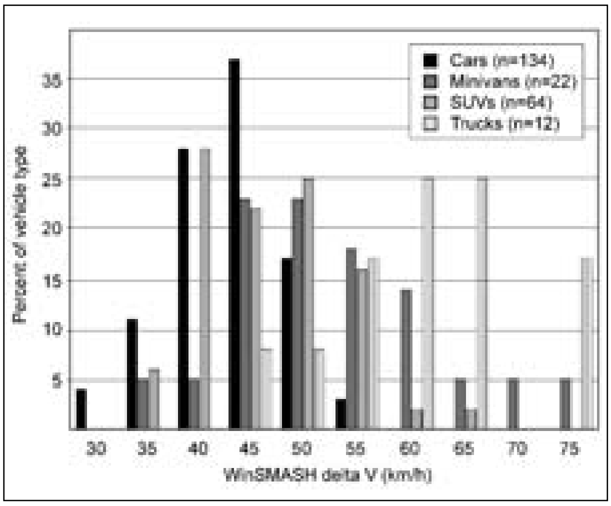


Figure 1: Histogram of estimated delta Vs for IIHS tests

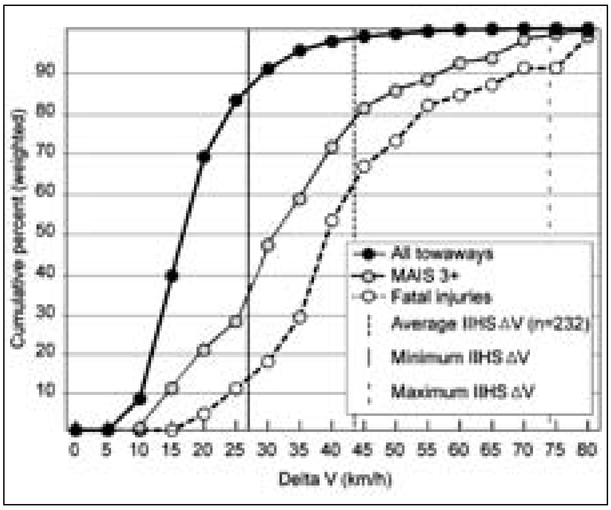


Figure 2: Cumulative distribution of delta Vs by injury level

Figure 2 compares the range and average of SMASH delta V estimates for crash tested vehicles with the delta V distribution of crashes in NASS. Just under 80 percent of MAIS 3+ injuries and slightly more than 60 percent of fatalities occur at or below a delta V of 44km/h. The wide range of delta V estimates for the tested vehicles (27 to 74km/h), however, indicates considerable uncertainty as to which portion of the NASS crash distribution is most similar to the laboratory crash test.

Discussion

The underestimate and wide variation of the crash test delta V resulting from SMASH calculations largely are due to the use of inappropriate vehicle stiffness estimates contained in the generalized stiffness categories. For instance, the 1996 Toyota Previa and 1996 Mazda MPV had similar test weights and are assigned the same stiffness category in SMASH. The SMASH estimated delta V for the Previa was only 47km/h while the estimated delta V for the MPV was 72km/h. These results indicate that the Previa is much stiffer than the MPV and should not have the same categorical stiffness. Furthermore, the stiffness value to which both vehicles are assigned is not particularly representative of the actual stiffness of either vehicle. Previous studies showed that the delta V estimation would be more accurate if the vehicle-specific stiffness coefficients were used [3], but NASS delta V estimates continue to be based on the generalized stiffness categories [7]. This practice leads to considerable uncertainty in relating laboratory crash tests to the real-world counterparts in NASS.

The large number of crash tested vehicles for which SMASH delta Vs were made in this analysis allows a good estimate of the general severity of the test. Almost 80 percent of serious injuries and more than 60 percent of fatalities in real-world offset crashes occur at or below the average delta V estimated for the IIHS frontal offset test, reconfirming that the test is similar to the kinds of real crashes that cause serious injuries and sometimes cause occupant deaths. Manufacturers have responded to IIHS tests with major improvements to vehicle structure, so that the range of performance has narrowed. Most vehicles now perform very well and research shows that vehicles with better ratings provide better occupant protection in the real crashes [8].

References

1 Insurance Institute for Highway Safety: Crashworthiness evaluation offset barrier crash test protocol, version XI, Arlington, VA, 2004

2 J.M. NOLAN, C.A. PREUSS, S.L. JONES, B. O'NEILL: An update on the relationships between computed delta Vs and impact speeds for offset crash tests, Proceedings of the 16th International Technical Conference on the Enhanced Safety of Vehicles, pp. 1234-41, National Highway Traffic Safety Administration, Washington, DC, 1998

3 B. O'NEILL, A.K. LUND, D.S. ZUBY, C.R. ESTEP: New vehicle crashworthiness evaluations by the Insurance Institute for Highway Safety, Proceedings of the 15th International Technical Conference on the Enhanced Safety of Vehicles, pp. 2030-39, National Highway Traffic Safety Administration, Washington, DC, 1996

4 B. O'NEILL, C.A. PREUSS, J.M. NOLAN: Relationships between computed delta V and impact speeds for offset crash tests, Proceedings of the 15th International Technical Conference on the Enhanced Safety of Vehicles, pp. 1433-40, National Highway Traffic Safety Administration, Washington, DC, 1996

5 B. O'NEILL, A.K. LUND, D.S. ZUBY, C.A. PREUSS: Offset frontal impacts – a comparison of real-world crashes with laboratory tests, Proceedings of the 14th International Technical Conference on the Enhanced Safety of Vehicles, pp. 649-70, National Highway Traffic Safety Administration, Washington, DC, 1994

6 National Highway Traffic Safety Administration: National Automotive Sampling System, 1997-2004, US Department of Transportation, Washington, DC, 2005

7 D.A. AYLOR: Personal communication, Steve Mavros, National Highway Traffic Safety Administration, June 9, 2006

8 C.M. FARMER: Relationships of frontal offset crash test results to real-world driver fatality rates, Traffic Injury Prevention, vol. 6, pp. 31-37, 2005

F. Kramer, R. Werner, J. Reimer
Automotive Engineering, Mechanical Engineering and Technology, University of Applied Sciences, Dresden, Germany

Safety Criteria System: An Opportunity of Focussing Different Dummy Loading Values to a Single Expression

Abstract

The degrees of injury severity, as a rule injuries scaled by AIS of specific regions of the human body, investigated out of road traffic accidents correspond to the body-specific loading values, which are found out with the aid of experimental or mathematical simulation of crash tests with motor vehicles or with sled tests. The coherence between the injured human being on the one hand and the physical and the theoretical model respectively on the other hand is established by the risk function, which describes the probability of degrees of injury severity in dependence on the protection criteria. Due to the different physical characteristics in the simulation, e.g. accelerations, forces, compressions and their velocity, the compilation of these quantities, comparable to the MAIS, the maximal occurred single AIS obtained in accident analysis is much more difficult in the simulation than in the accident occurrence. Therefore it is obvious to normalize the loading values gained out of simulation and to summarise them to an entire value in a suitable manner, the safety index.

Introduction

For the processing of the safety index, results are used from accident statistics as well as from biomechanical research: the analysis on accidents provides the relevance structure which considers the significance of the loading of particular body regions due to their injury probability. The necessary risk functions with the protection criteria are derived from the biomechanical research, whereas the protection criterion level with a probability of 50 percent for reversible/non-reversible injuries is regulated by law.

After the transfer of the risk functions into the evaluation functions, all body-specific safety degrees can be summarised to a safety index. With the safety index the experimentally or mathematically determined loading values were focused to only one value, in which biomechanical phenomena and injury-statistical aspects were considered. It allows an objective assessment of the efficiency of safety systems for occupants and pedestrians and permits a reliable estimation of the inside and outside secondary (passive) safety of motor vehicles by the aggregation of current safety indices.

The Theoretical Approach

The described procedure, in which the acquired approach of a research project [1] sponsored by the BASt has been continued, includes the constraints for the safety criteria system in form of risk functions with legal regulated protection criterion levels, the evaluation functions derived from risk functions, and the relevance structure from the accident occurrence for weighting of the body-specific safety degrees. All these portions are used for the aggregation to the safety index.

The utilisation of risk functions

With the aid of a comprehensive literature research [2] currently existing and published risk functions for

Body region	Protection criterion	Protection criterion level	Legal requirements
Head	HIC	1.000	ECE R-94, ECE R-95
	a_{3ms}	80g	
	HIC	390 up to 700	FMVSS 208
Neck	N_{ij}	1,0	FMVSS 208
Thorax	a_{3ms}	50 up to 60g	FMVSS 208
	Compression	30 up to 63mm	
	a_{3ms}	60g	ECE R-94
	Compression	50mm	
	RDC	42mm	ECE R-95
	VC	1,0m/s	FMVSS 208; ECE R-94, ECE R-95
	TTI	85g or 90g	FMVSS 214
Abdomen	$F_{lateral}$	2,5kN	ECE R-95
Pelvis	$F_{pubic\ symphysis}$	6,0kN	ECE R-95
	a_{max}	130g	FMVSS 214
Femur	F_{longit}	6,8 or 10,0kN	FMVSS 208
Knee	Deflection	15mm	ECE R-94
Tibia	F_{longit}	8,0kN	ECE R-94
	TI	1,3	ECE R-94

Table 1: Legal protection criteria and protection criterion levels used in the Safety Criteria System

seven body regions and legal regulated protection criteria for frontal and side crash tests as well as for pedestrian impact tests are included (Table 1). The separation between AIS 2 and AIS 3 for the head and the extremities and between AIS 3 and AIS 4 for the other body regions allows the distinction of the probability for reversible and irreversible injuries. In order to facilitate a closed-ended mathematical formulation of the body-specific risk function, it is approximated with the aid of a lognormal distribution which can be described in each case only by two different variables.

Evaluation functions

The evaluation function is achieved by the inversion of the risk function, i.e. a reflection and a dilation, and contains a range of values for the safety degree of SG_i=1…-1. The value 1 features the maximally attainable safety level and the safety degree of SG_i=0.0 results from the standardised loading value NBW_i=1. The size offered on the abscissa is the standardised loading value, the quotient of the measured or calculated loading value and the protection criterion level, i.e. the standardised loading amounts to the value 1, if the current loading value is equal to the protection criterion level.

Relevance structure

The relevance structure is used for the weighting of the body-specific safety degrees and is determined as probability out of the accident occurrence depending on the accident type (frontal or side impact), of the seat position and of the size of the occupant (adult or child). The sum of the used weighting factors for the maximal possible seven body regions (head, neck, thorax, abdomen, pelvis as well as upper and lower extremities) is added together to 1 (according to 100%). If only a lower number of selected body regions are considered in the simulation, the relevance structure is adapted to 100%.

The compilation of the safety index out of safety degrees

In order to calculate the safety index, the safety degree of each body region (head, neck, thorax, arms, abdomen, pelvis and legs) will be multiplied by the weighting factors according the relevance structure and aggregated to the safety index SIX. Since the safety index SIX consists of the sum of all weighted safety degrees SG_i, it reaches values between SIX=1...-1 too. The safety index SIX=1 labels the highest stage of the secondary (passive) safety. If for a body region a high safety degree is reached (SG_i>0) and for an other higher loaded body region the degree of SG_j<0, the different safety degrees can be balanced and in the sum still become a positive safety index of SIX>0. However, from that comprehensive, reliable analysis of the simulation results besides the safety index SIX also the original loading values should be retained and considered in order to be able to assess deficiencies of individual safety measures and to be able to introduce corresponding improvements.

Application of the Safety Index

In the following presented application of the safety criteria system, the dummy loading values are determined of EuroNCAP crash tests for frontal and side impacts with 13 vehicles of different types [3]. On the one hand the evaluation with credit points is determined for loadings at the head, the neck, the thorax, the abdomen and the pelvis of the drivers according to the EuroNCAP conditions and on the other hand with the aid of the safety criteria system the safety index SIX is calculated. In Figure 1 the determined results are shown for the test configurations with each vehicle. Apart from two exceptions they show an outstanding agreement. The shown deviations are based on the two procedures underlying different approaches at the evaluations of the loading values and the weighting of the significance of accidents injured body regions: while with the EuroNCAP procedure

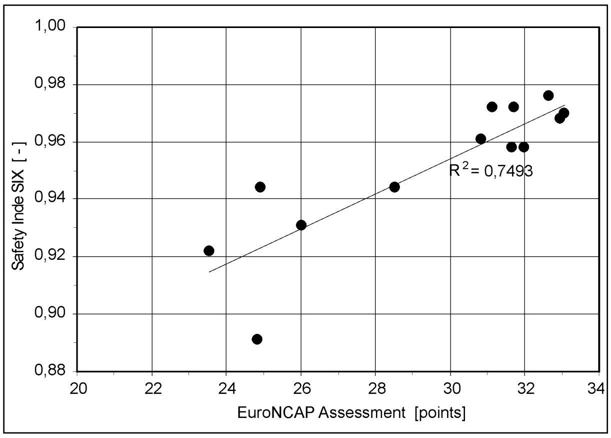


Figure 1: Comparison between the EuroNCAP assessment (points without seat-belt reminder) and the safety index based on the safety criteria system

specific points are being assigned to loading value ranges, the application of risk functions within the safety criteria system allows a continuous assignment between the body-specific loading values and the corresponding safety degrees. Furthermore, in the safety criteria system the individual body regions are weighted according to their injury probability, whereas in the EuroNCAP procedure the injury relevance remains unconsidered.

References

[1] H. APPEL, F. KRAMER, W. GLATZ, G. LUTTER: Quantifizierung der passiven Sicherheit von Pkw-Insassen. Technische Universität Berlin. Bericht zum Forschungsbericht 8517/2 der Bundesanstalt für Straßenwesen (Hrsg.). Bergisch Gladbach, 1991

[2] W. REIMER, R. WERNER: Die Bewertung der passiven Sicherheit bei relevanten Kollisionen mit Hilfe des Sicherheitskriterien-Systems (SiKriS). Diplomarbeit an der HTW Dresden, 2005

[3] A. SEECK: EuroNCAP-Ergebnisse (Stand: 10.10.2005). Bereitgestellt als Excel-Datei. Bergisch Gladbach, 2005

Session:
Accident Prevention and Causation

B. Pund, D. Otte, M. Jänsch

E. Tomasch, H. Steffan, H. Hoschopf, A. Moser

D. Patel, M. Ross, C. Compton, T. Wenzel

Y. Page, P. Thomas, V. Hervé, A. Kirk

P. Thomas

M. Hoppe, M. Junge, M. Jungmichel, K. Seifert

B. Pund
TUEV Nord Institute for Traffic Psychology,
Hannover, Germany

D. Otte, M. Jänsch
Accident Research Unit Medical School Hannover,
Germany

Systematic of Analysis of Human Accident Causation – Seven Steps Methodology

Abbreviated System for the Assessment of Accident Causation in In-Depth Accident Studies

Abstract

The "Seven Steps Method" is an analysis and classification system, which describes the human participation factors and their causes in the temporal sequence (from the perceptibility to concrete action errors) taking into consideration the logical sequence of individual basic functions. By means of the "seven steps" it is possible to describe the relevant human causes of accidents from persons involved in the accident in an economic way with a sufficient degree of exactitude, because the causes can be further differentiated in their value (e.g. diversion as external diversion with regard to impact due to surroundings) and their sub values (e.g. external diversion with regard to impact due to surroundings in the shape of a "capture" of the perception by a prominent object of the traffic environment). Theoretically it is possible that one or more causing moments can be assigned to a person involved in an accident in each of the "seven steps"; however it is also possible to sufficiently clarify the cause in only one level (examples for this are described).

In the practice of accident investigation at the site of the accident, the sequence chart is also relevant. With its assistance the questioning of the people involved in an accident can be accomplished in a structured way by assigning a set of questions to each step.

Introduction and Objective

Due to the constant decrease of the casualties and fatalities arising from traffic accidents, questions regarding the possible accident avoidance potential come into the foreground. Also the implementations of many technical sensors and systems into the new vehicles for the simplification of actions and navigation assistance when guiding a motor vehicle through increasingly dense traffic can cause misinterpretations and spurious actions of the drivers. This has to be recognized for a future optimization of measures and has to be acted on. Requirements of a scientifically oriented accident research increase and have to be focused on the causes of accidents. The interests of the team active at the site of the accident immediately after such an event has taken place have to be taken into consideration. On the one hand the road user is still in place, and on the other hand cannot always be pursued at a later stage due to costs. For this reason, a special procedure using special questions was developed in the course of the on-scene accident investigation in Hannover (GIDAS German in-Depth Accident Study). This procedure makes it possible also for a non-psychologist to compile a substantial amount of information from the persons involved, in order to be able to better determine the cause of the accidents and to facilitate the coding for data storage at a later stage. An initial approach was introduced during ESAR 2004 [1]. Based on this foundation further developments of purposeful questioning were conducted locally. The results of which are presented now on the occasion of the ESAR 2006.

A systematic scheme for the analysis of the humanly accident causes by investigations at the site of the accident should include the following four characteristics:

- The structure is to be oriented at the temporal sequence of the human functions and processes in the seconds before the accident: initial conditions (e.g. functional restrictions of the perception ability), perception (attention, registration of the situation), judgment (risk assessment, avoidance planning) and acting (action design, execution, driving manoeuver).
- Each analysis step shall be clearly definable and clearly feasible by test criteria of which the causes are ascribable to associated human processes and basic human functions.

- The structure of the analysis model shall exhibit an accordance as high as possible with the structure of the questionnaire for application at the site of the accident or with the subsequent questioning, in order to ensure an internal logic for a time-economic and “intuitive” questioning.
- This way together with other cause factors from the domain ‘vehicle technology or road infrastructure’ the answers and results of the analysis can be uniquely assigned to an analysis step of the flow chart and in coded form, serve to describe a certain type of cause.

The set-up of the procedure and analysis model of “7 steps” took place due to earlier theoretical considerations [1] and via adjustment of psychological models for the causes of accident to the requirements of “in-Depth"/"on-Site” analyses on accidents with the emphasis on the recording and description of the humanly caused influences and their interaction with the conditions of the vehicle and the driving environment [2-4].

Practical experiences by questioning people involved in accidents influenced the structure of the model, in particular in view of the handling of the model in the shape of a semi-standardized questionnaire.

The structure of the Sequence and Analysis Model

In order to avoid reductionistic statements about causes of accidents, the common causes (e.g. “inattentiveness") were defined as determinators (decision criteria) on the basis of which human cause factors described in traffic-psychological literature are identifiable (e.g. kind of the diversion, which leads to the restriction of the attention).

The required model explicitly covers the identification of the type of error or mistake of the person involved in the accident in the pre-crash phase besides an as exact description of the human cause factors as possible by feature categories in each analysis step. To that extent the

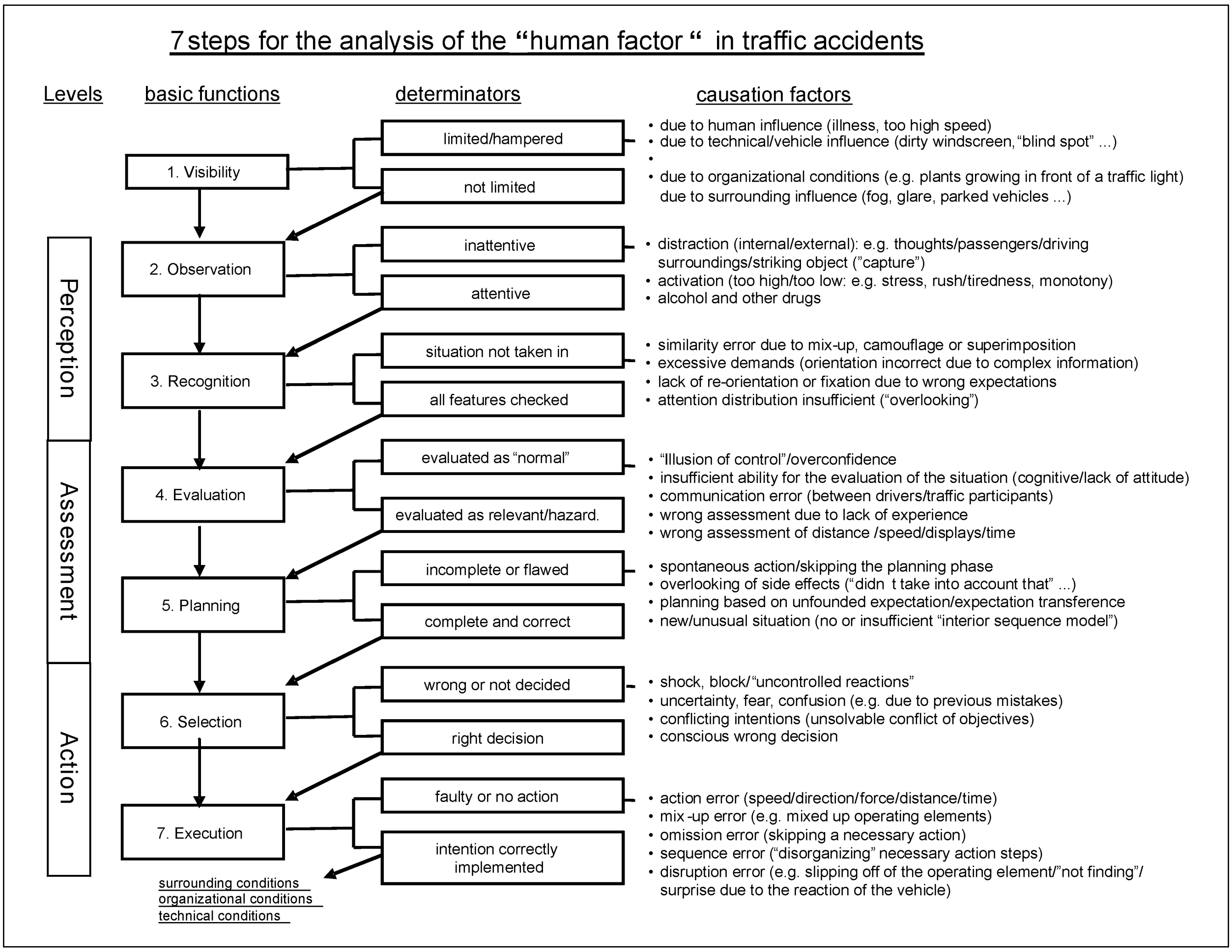


Figure 1: Method structure of the analysis model

model of the “7 steps” also has a theoretical proximity to well-known findings of the error analysis (e.g. [5, 6]).

Following the awareness of the multiple determination of accidents, the model can be used to identify accidents causes and/or errors in several steps on the one hand; in other accidents the analysis can end at only one certain step, because the cause may be assignable with a sufficient degree of certainty. A schematic representation of the method structure is represented in Figure 1.

In order to prevent a too fast interpretation as well as “obviousness” and to prevent overlooking ‘hidden’ causes, however, a questioning as complete as possible and an analysis based on all 7 steps is appropriate. If the interviewer adheres to the questioning pattern derived from the model, the specific answer of the person involved in an accident can be assigned to a step of the model at a later assignment. Possible false assessments can be avoided by the fact that the basic function involved is analyzed. The statement “I thought that nothing would happen” for instance can be assigned either to Step 4 (confidence error) or to Step 5 (overlooking side effects).

An exact assignment can be gleaned, if the question is asked whether this error arose when estimating the risk of the situation or if the risk was recognized, in the next step of the planning of the avoidance reaction. In our example the person asked answered that he had not noticed that another vehicle was driving next to his own car during the instigation of his evasion manoeuver. This elaboration shows that this cause has to be coded as Step 5 as well, because he neglected “side effects” in his action design.

The coping with a traffic situation/a traffic conflict/a hazard constellation presupposes an unhindered information access on side of the road user. The “7 steps” therefore start with a simple analysis of the perception conditions at the site of the accident and the perception potential of the person involved in the accident, as represented in Figure 1.

Accident Causation Analysis with Seven Steps ACASS

First Step: Did the road user objectively have access to the relevant information (or could he have had)? What prevented him from access to the information?

The evaluation of perception-restrictive conditions can refer on the one hand to clearly recognizable characteristics (e.g. vegetation in front of a traffic light). On the other hand, the entire perception condition can play a role in the analysis of the causes of accidents (e.g. dense fog, sun glare). In the latter case it is assumed that the access to information for the road user was at least difficult (e.g. despite darkness), however cause factors of the following analysis steps will also play a role. Furthermore, restrictions of the assimilation of traffic-relevant information can be caused by influences due to the vehicle (e.g. structural units or additional load) or organizational conditions of traffic (blocked view). After all, the functions of the human sensors and the efficiency of the peripheral nervous data processing system determine the availability of traffic-relevant information. Here long-term health problems limiting perception (e.g. central and peripheral amblyopia) are of importance.

The influence of the selected speed also falls under the first analysis step, as at an increased speed situation details and situation changes are less well perceptible, even with increased attention.

The cause factors connected with reduced attention are collected in the second step, where in contrast to the first step with the acquisition of long-term influences of human perception, here currently effective cause factors are important: diversion, activation and alcohol/drugs.

The further analysis at the site of the accident deals with the question, of whether the person involved in the accident, after the perception possibilities were given in all likelihood, has also attentively observed critical or relevant elements of the situation before the accident or whether he could at all, e.g. was he prevented due to the influence of alcohol. Furthermore, the reasons for a lack of “observation accuracy” can consist of a diversion, which can be caused both internally (e.g. diverting thoughts) and externally (e.g. discussion with passengers, diverting attractions in traffic). Attention can be tied also by the fact that the driver and/or road user is either too strongly activated (nervousness, stress, hurry) or the activation is too low (tiredness, circadian rhythm, driving under monotonous conditions). A special case of an extreme diversion is called “capture": the entire attention is focused on a “pre-dominant” event or object.

The answer frequently given by people involved in an accident to have “overlooked” something in traffic is assigned to the third step: the situation was not completely grasped, e.g. because of an insufficient distribution of the attention or a missing re-orientation towards the possible source of danger due to unfounded expectation of the situation development.

In this step it is assumed that despite attentive observation it is not automatically ensured that the road user also recognizes what the situation or a situation detail means regarding to the solution of a traffic conflict. The identification can also be limited by the fact that relevant situation characteristics cannot be differentiated ("fusion”, “camouflage") or that a mistake is made due to the similarity to other objects. Furthermore, the identification can be prevented by excessive demands. The driver does not orientate sufficiently, because he is overtaxed either by the situation as such or by individual details (complex information transfer). The complexity of the information transfer is classified on the basis of a classification scheme by the analysis of the perception conditions at the site of the accident.

However, if the relevant characteristics of the accident situation were recognized, in the fourth step the question is to be raised by the interrogator, whether the road user judged the situation properly.

The most frequent false assessments here refer to the fact that the road user judged certain elements of the traffic situation as not relevant or not risky, even though no “normal situation” is present, but a need for orientation within a critically changed situation. False assessments can refer here to distances, speeds, space situation or indicated information, furthermore faulty assessments due to a lack of experience or inadequate transfer of experiences from similar situations can occur. In this step of the analysis, the “illusion of control” also comes into effect: the driver accepts a high risk, since he thinks that he can deal with the traffic situation without problems. The driver simply has excessive faith into his own abilities or into the trouble-free development of the traffic situations. Further causes and/or assessment errors lie in the inability of the involved person to properly judge the situation or in communication errors between road users.

The fifth step of the causation analysis refers to the usually very short phase of the planning of behavior options, if the situation were assessed as risky or relevant.

If the interrogator should have indicators for the fact that the person involved in accident was surprised “out of the blue” by the sequence, it must be assumed that the time was not sufficient for the planning of behavior (e.g. “I could not think straight"). Furthermore, it may be that sufficient time was given for the execution of an action design, the traffic participant however had wrong expectations ("that’s the way it always was") or ignored secondary effects (e.g. “I had not expected him to start off..."). A further “mistake in reasoning” can be present in those cases, where the road user had a wrong “mental” model of the sequence of situation, e.g. because the situation is unknown or unusual to him.

The sixth step of the causation analysis covers the decision which the driver drew from the previous planning step.

Here it may be possible that the road user either did not decide on anything or decided wrongly against his previous conclusion. The causes may on the one hand be derived from shock symptoms (shock, block, “uncontrolled reactions"), which prevent purposeful actions, on the other hand fear and confusion may prevail, e.g. due to a chain of preceding errors. A wrong decision for or against an action can also be that the road user was unable to decide between two equivalent goals, thus was caught between unsolvable conflicting aims.

However, if the road user decided correctly, the errors can be due to the concrete actions taken and/or their execution in the seventh step.

If the road user did not act properly or not at all, an execution error is usually present, whereby the interviewed person acted erroneously concerning speed, strength, direction or distance. Further errors in the execution refer to mix-ups, omissions, wrong sequence in actions as well as to interrupted actions (e.g. surprise due to the intervention of the vehicle assistant or the “non--finding” of a control element). The concrete avoidance reaction is also systematically recorded, according to kind of driving maneuvers and their qualitative value (e.g. abrupt braking in combination with swerving to the right).

The analysis of the “human factor” in traffic accidents ends with this seventh step, where the analysis is continued, should the road user have acted “correctly” according to the analysis. (Expansion of Seven Steps).

Here in principle two possibilities are conceivable for the further analysis steps, which can also be present simultaneously: the organizational, environmental or technical conditions are faulty and/or the causing part is with the collision partner.

The method of the "7 steps " has the advantage of recording the internal processes of human behavior to such an extent that during the inquiry at the site of the accident a clear and appropriate cause can be established very quickly. This possibly cannot be recognized in as much detail as by means of an isolated deep-psychological questioning. For the work at the site of the accident is it extremely important to be able to change the questioning process dynamically or to terminate it completely. The interrogator can terminate the questioning, if he found a clear allocation of a cause of accident to one level of the "7 steps". Nevertheless a further analysis can take place at a later time, in order to find further causes of the accident; to that extent the alternatives at the point of decision, whether in the respective step a significant cause is present or not, are to be seen rather as a working hypothesis. Thus in addition to the decision, whether the driver was inattentive or attentive (2nd step) from his reports "inattentiveness by diversion", a further cause could be present (additionally e.g. a communication error, see step 4) in the following phases.

Case Study: Example of the Application of the Seven Steps Method for the Purpose of Analyzing and Classification of the Causes

Case 05-928, in the village Heessel, rural Lower Saxony in the district Hannover, on November 22nd, 2005, around 5.40 p.m.: a passenger car of the type Mercedes turns left from a local road on the privileged through road 188 (village street) and collides with a motor cycle of the make Yamaha coming from the left. See Figure 2 for a sketch of the accident site.

At the time of the accident it was already dark. The pictures 1 and 2 show the view of the car driver approaching the junction, once at night with artificial lighting and once during daytime. In picture 3 you can see the perspective of the car driver when looking to the left. The picture was taken from behind the bus stop. In the background you can see the lights of a petrol station. Picture 4 shows the view to the left of the car driver directly at the junction, however, taken at daytime. The view of the approaching motorcycle rider can be seen in picture 5. The damages of the car (picture 6) show that the car ran into the side of the motorcycle which was coming from the left.

The results of the retrospective questioning resulted in the following classifications into the "7 steps":

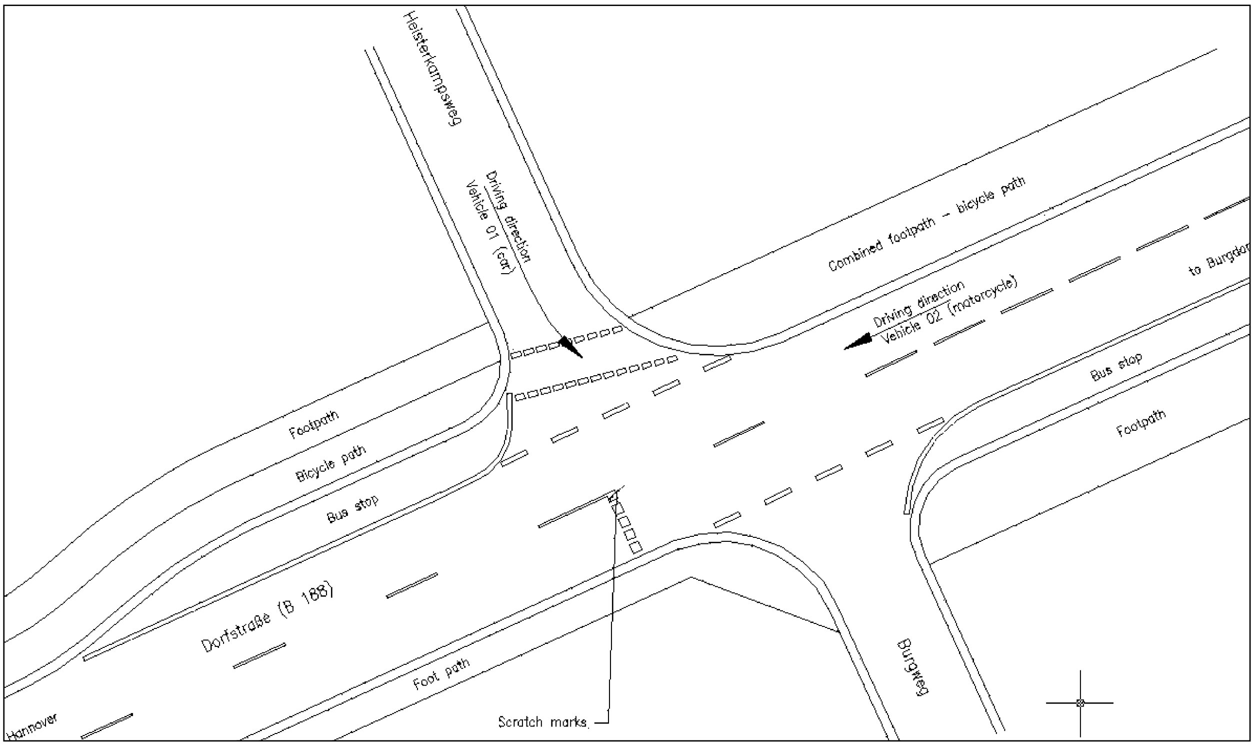


Figure 2: Sketch of the accident site

In the first step the driver was asked about the perception conditions. “Everything was just as always, only somewhat dark and murky… no rain, but the roads were somewhat moistened, no one was in front of me and none behind me... the only exceptional thing was that the road was free for me on both sides, the 188 is usually always busy.” Also, as no illness-related or visual problems were present, in the second step the degree of attentiveness was of interest: “I had started at home and was on my way to play tennis; it was just like always... I had twenty minutes to cover a distance of 5 kilometers, thus I was rested, relaxed, everything was fine... approached the 188, coming from the Heisterkampsweg, I looked to the right, no vehicles approaching from any direction, no headlight to be seen, I looked to the left, saw nothing, started slowly across the intersection.” As questions concerning diverting conditions were also answered in the negative, in the third step it was asked whether the situation was completely taken

Picture 1: View of the car driver approaching the crossing

Picture 2: Same view as in Picture 1, during daytime

Picture 3: Car driver’s view to the left. (picture taken from behind the crossing)

Picture 4: Car driver’s view to the left at the crossing

Picture 5: View of the motorcycle rider approaching the crossing during daytime

Picture 6: Damages on the car

in briefly before the accident: “I do not know. I have sorted everything in my head and am of the opinion that I did not identify the headlight of the motorcycle as a headlight. Simply because it was a light that belonged there anyway. Because there in the back in this corner there is a gas station, it is also very brightly lit and the light was assimilated. It must have approached me directly from ahead, thus it did not seem to move and therefore I imagined it to be a lamp. When it swerved, I noticed the fact that the thing itself moved of its own and then everything was already history.” Here a cause factor due to incorrect identification was assumed: Coding 3.1 (third step “recognition"; similarity error due to mix-up, camouflage or superimposition). In the course of further questioning it was found that the driver made no assessment or interpretation error in the fourth step, as he interpreted the risk as such correctly, however too late: “In one instant I saw a lamp, which moved and then I identified it as a motorcycle, I stopped, but the motor cyclist was no longer able to take evasive action, to avoid hitting me. He slightly touched the front of my car at the bumper and there received the jolt”. A possible error in the planning of the avoidance reaction (fifth step) could be excluded. His planning concerning the possible emergency reaction was correct. In the sixth step no decision problem could be found, as the decision to break at the moment the danger was recognized was correct. Decision errors due to shock phenomena or due to conscious wrong decisions did not arise. A seventh step does not apply here any longer, as no execution errors are recognizable, when he recognized the danger he stopped his vehicle immediately. The concrete driving maneuver “braking” is determined in the coding pattern for the description of the avoidance reactions and possible combinations of the same.

Conclusion and Outlook

Derived from practical experiences when questioning at the site of an accident a hierarchical system was developed for the recording and evaluation of human influences causing traffic accidents with the background of psychological error analysis. The methodical procedure follows a system, which images the relevant perception, evaluation and action processes from the view of each person directly involved in the accident on the basis of an analysis of the perception conditions. The perceptive, cognitive and motor processes effective on these three levels are determined more closely in each case in two subcategories (basic functions), so that sequence systematics including the base function ("perception possibilities") covers seven steps altogether. The “7 step method” is an analysis and order system, which describes the human participation factors and their causes from the temporal sequence (from the perceptibility to concrete action errors) with consideration of the logical sequence of individual basic functions. The model is influenced by the idea of interactive accident models as an analysis method of the human information process (cognitions, actions and errors interacting with the environment; e.g. [7]). Furthermore it refers to dynamic sequence models (e.g. [7-9]) and emphasizes the functioning of human processes on their regulation levels and the subsequent errors (e.g. [5]). With assistance of the “seven steps” it is possible to further describe the relevant human causes of accidents of persons involved in the accident with a sufficient degree of exactitude in an economic way, because the causes can be further differentiated in their value (e.g. diversion as external diversion with regard to surroundings) and their subvalues (e.g. external diversion with regard to surroundings in the shape of a “capture” of the perception by a prominent object of the traffic surroundings). The “seven-step-method”, also called ACASS Accident Causation Analysis with Seven Steps, represents a practical analysis system, which is easy and simple to apply by scientific recording teams in the course of in-depth investigations and allows an allocation to possible causes of accidents in a fast analysis in form of a screening procedure. It must surely be regarded as a simplified kind of analysis according to psychological criteria, as in this way no background of deep-seated human behavior error is recognizable. ACASS, however, explicitly covers the identification of the kind of the error or mistake in the pre-crash phase by the person involved in an accident, besides an as exact as possible description of the human cause factors by feature categories in every analysis step.

ACASS offers a logical questioning pattern that can be used to determine the possible cause factors in their temporal sequence. This also facilitates the mental reconstruction of his course of action for the interviewed person concerning the setting-off of the accident and its avoidance. The practical application of ACASS also supplies room for future advancements of the system in the following points:

- the extension of possible cause factors of the individual steps of the human factor and the codability of these factors, e.g. for the recording of the causes within a data base system,
- the recording and coding bar of extended possible causes of accidents from the areas organizational, environmental, action-specific and technical causes, in particular in view of the modules of telematics, which will be found in vehicles in the near future.

ACASS is also suitable to be integrated into these extensions.

References

1 B. PUND, D. OTTE: Assessment of Accident Causation from the Viewpoint on In-Depth Investigation on Scene – Traffic Psychological Methodology on Examples of In-Depth Cases by GIDAS. In: Reports on the ESAR-Conference on 3rd/4th September 2004 at Hannover Medical School, Berichte der Bundesanstalt für Straßenwesen, Heft F 55, 2005.

2 D. OTTE: The Accident Research Unit Hannover as Example for Importance and Benefit of Existing In-Depth Investigations, SAE 940712, 1994

3 B. PUND, W.-R. NICKEL: Psychologische Untersuchungen am Unfallort. Berichte der Bundesanstalt für Straßenwesen, Heft M 27, 1994

4 B. PUND, D. OTTE: Zusammenführung von technischen, medizinischen und psychologischen Erkenntnissen bei der Unfallerhebung vor Ort. In: F. MEYER-GRAMCKO (Hrsg.), Verkehrspsychologie auf neuen Wegen: Herausforderungen von Straße, Wasser, Luft und Schiene. Bonn: Deutscher Psychologen-Verlag, 1999

5 J. RASMUSSEN: The Concept of Human Error and the Design of Reliable Human-Machine-Systems. In: H.P. WILLUMEIT & H. KOLREP (Hrsg.), Verlässlichkeit von Mensch-Maschine-Systemen, S. 255-271, Berlin: Technische Universität Berlin, 1995

6 J. REASON: Menschliches Versagen: Psychologische Risikofaktoren und moderne Technologien. Aus dem Amerikanischen übersetzt von J. GRABOWSKI. Heidelberg: Spektrum Akademischer Verlag, 1994

7 Chr. HEINRICH, K.M. PORSCHEN: Die Bedeutung interaktiver Unfallmodelle für die Straßenverkehrssicherheitsforschung, Zeitschrift für Verkehrssicherheit 35, 1989

8 G.L. McDONALD: The Involvement of Tractor Design in Accidents, Research report 3/72, Department of Mechanical Engineering, University of Queensland, 1972

9 H.J. KÜTING: Zur Analyse von Denk- und Handlungsfehlern beim Autofahren, W.-R. NICKEL (Hrsg.), Fahrverhalten und Verkehrsumwelt, Köln, Verlag TÜV Rheinland, 1990

10 J. SURRY: Industrial Accident Research: A Human Engineering Appraisal, University of Toronto, Department of Industrial Engineering, 1969

E. Tomasch, H. Steffan, H. Hoschopf
Vehicle Safety Institute, Graz University of Technology, Graz, Austria

A. Moser, DSD, Linz, Austria

Comparsion of Single Vehicle Accidents with Cars not Equipped with ESP (Electronic Stability Programme) and the Assumption the Cars are Equipped with ESP

Abstract

In recent years the boundaries between active and passive safety blurred more and more. Passive safety in the traditional term includes all safety aspects to prevent occupants to be injured or at least injury severity should be reduced. Passive Safety starts with the collision (first vehicle contact) and ends with rescue (open vehicle doors). Within this phase the occupant has to be protected by the passenger compartment whereby no intrusion should occur. Active safety on the other side was developed to interact prior to the collision whereby the goal is to prevent accidents. The extensive interaction between active and passive safety led to the terminologies “Primary” and “Secondary” safety whereas the expression Integrated Safety Concept [1] was generated.

Within this study the most well documented single vehicle accidents with cars not equipped with ESP were identified from the PENDANT database and reconstructed. Additional cases were found in the database ZEDATU of TU Graz. In comparison each case was simulated with the assumption that the cars were equipped with ESP. The differences regarding accident avoidance or crash severity as well as reduction of injury risk were analysed.

Introduction

This study is part of the PENDANT (Pan-European Co-ordinated Accident and Injury Databases) project [3]. The project itself is divided into three Work Packages. The Purpose of Work Package 1 was to ensure that in-depth accident and injury data collected by several organisations were comparable. In particular two tasks addressed the needed harmonisation of the fundamental crash parameters describing collision severity and injury outcome. The third task analysed accident causation and injury countermeasures. Within Work Package 2 the teams of eight different countries were collecting approximately 1,100 accidents. A database was developed based on an enhanced STAIRS (Standardisation of Accident and Injury Registration Systems) protocol [2]. Work Package 3 investigated existing hospital data from three countries. This type of data covered relevant injury data, treatment data and normally some general accident data of traffic casualties admitted to hospitals.

Task 3 in Work Package 1 investigated active safety even if the whole project was primarily focussing on passive safety aspects. The most well documented 30 (if available) single vehicle accidents with cars not equipped with ESP should have been identified from the in-depth database collection in Work Package 2 [4].

Due to the emphasis on passive safety the goal of 30 well documented single vehicle accidents was not reached. An additional investigation has been made in the ZEDATU (Zentrale Datenbank tödlicher Unfälle) database from TU Graz. Within this database fatal accidents from 2003 are examined. Finally 26 accidents were found in total meeting the high requirements.

In the first step, accidents were reconstructed and in a second step the assumption was made that the vehicles were equipped with ESP (Electronic Stability Programme). Accident avoidance possibilities and crash severity were documented.

Procedure

When the task started the PENDANT database had 958 accident case entries but not every accident investigation was finished. From notification of an accident by police until gathering injury data several weeks or even month may have elapsed. Approximately 44% of the collected accidents were single vehicle accidents and about 49% were accidents with two participating vehicles. In 7% of the accidents more than two cars were involved.

To facilitate the identification of single vehicle accidents the database was extended by a specific form according CARE Plus [5] data fields. Subsequent list presents the main groups of CARE Plus accident type configurations:

- Accident with pedestrians (group A).
- Accident with parked vehicles (group B).
- Single vehicle accidents (group C).
- Accidents with at least two vehicles and no turning (group D).
- Accidents with at least two vehicles and turning (group E).

As mentioned, main focus was set to single vehicle accidents. Figure 1 provides the distribution of all CARE accident types within the countries. Single vehicle accidents were most frequent in the United Kingdom sample as well as in the Spain cases. Another huge portion was found for French accidents. The amount of appropriate cases for Austria and Finland was limited.

Considering CARE glossary each main group is classified into subgroups and these subgroups are again divided into sub-subgroups defining a more detailed classification of the accident circumstances. In principle two subgroups can be distinguished in CARE main group "C" (represents level 3 in CARE Plus 2 accident type glossary) [10]:

Subgroup 1 (single vehicle accidents without obstacles on the road):

- C1L Single vehicle accidents without obstacles on the road – left.
- C1R Single vehicle accidents without obstacles on the road – right.
- C11 Single vehicle accident – leaving straight road – either side of the road.
- C12 Single vehicle accidents on the road (often two-wheelers).
- C13 Single vehicle accidents in a bend – going either side of the road.
- C14 Single vehicle accidents in junctions or entrances.
- C19 Single vehicle accidents – others.

Subgroup 2 (Single vehicle accidents with obstacles on the road):

- C2L Single vehicle accidents with obstacles on the road – left.
- C2R Single vehicle accidents with obstacles on the road – right.
- C21 Single vehicle accidents with animals.
- C22 Single vehicle accidents with obstacles on or above the road.

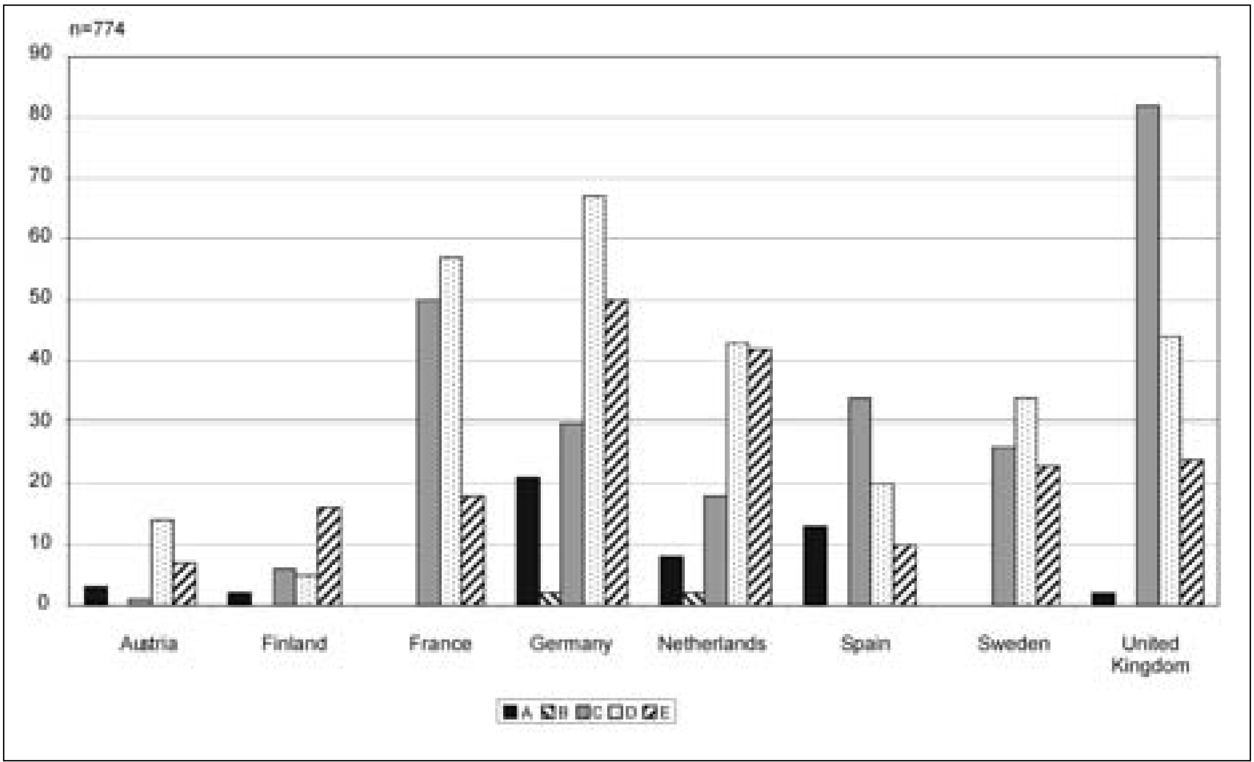


Figure 1: Case distribution CARE main group

- C23 Single vehicle accidents with roadwork materials.
- C24 Accidents between train and vehicle.
- C29 Single vehicles accidents with obstacles – others.

At this point about 254 cases were available for ESP investigation (Figure 2) whereby United Kingdom (32,68%) and France (20,08%) had the highest share. More than 50% of single vehicle accidents were collected in these two countries. Only a small number was found for Austria (0,39%) and Finland (2,36%). Spain had a share of 13,78%, Germany 12,60%, Sweden 10,24% and the Netherlands 7,87%. Due to the different relationships of investigation teams to police the differences could be explained.

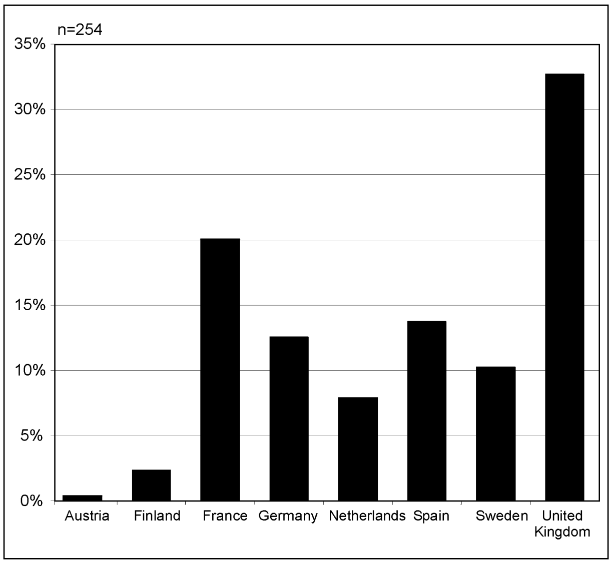


Figure 2: Accident cases CARE group C – partners

As already mentioned PENDANT focused on passive safety. Hence no pre-impact information was collected. In case of active safety only ESP (Electronic Stability Program), ABS (Antilock Braking System), TCS (Traction Control System) and ACS (Active Cornering System) were recorded as existing active safety features fitted to the vehicle. Even if there were data forms developed no attention was paid to generate guidelines to collect on-scene material. Besides PENDANT data forms only a few partners investigated in pre-impact evidence like skid marks, road design etc. anyway. Merely cases from Austria, Germany, the Netherlands and Sweden were available for the purposes of pre-impact investigation

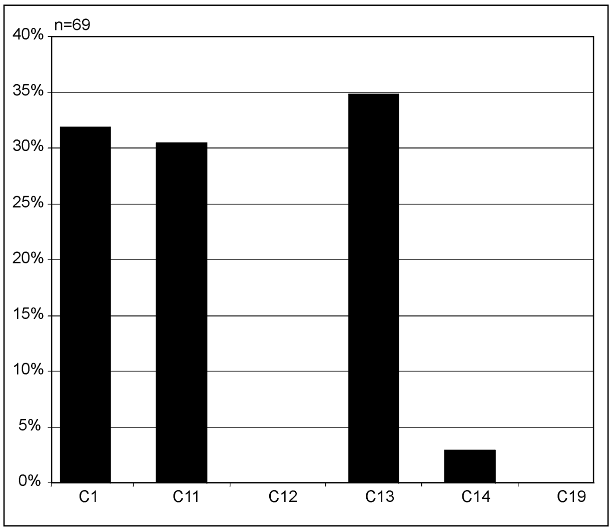


Figure 3: Single vehicle accidents CARE subgroup C1

Considering only subgroup 1 (which matched the requirements) and accident cases including. On-scene evidence 69 cases were left for in-depth studies (Figure 3). Eventually only 17 cases contained sufficient information. It has to be pointed out that not all single vehicle accidents are preceded by skidding. Vehicles already equipped with ESP were removed.

To increase the number of accidents the database ZEDATU (Zentrale Datenbank tödlicher Unfälle) of TU Graz was studied. Within the current datasets road-fatalities from 2003 were collected. Due to the accident coding system in Austria accidents vehicles skidding can be identified easily. At least one of the participating vehicles skidded in approximately 27% of 847 fatal accidents. Among accident circumstances “sideway skidding” and “forward skidding” are most frequent single vehicle accidents (53%, see Figure 4). Accidents with on-coming traffic had a share of 37%. 7% of these accidents were collisions between two vehicles driving in the same direction. All other types are negligible.

Gathering single vehicle accident cases from ZEDATU it turned out that documentation of accidents varied in quality. In particular pictures taken of scene and vehicles were inadequate. For a huge number of single vehicle accidents documentation had poor quality, especially when only the driver was involved. The reason can be found in Austrian’s legislation. There is no law to punish self-injuries – hence little effort is taken by the police in investigating single car accident thoroughly.

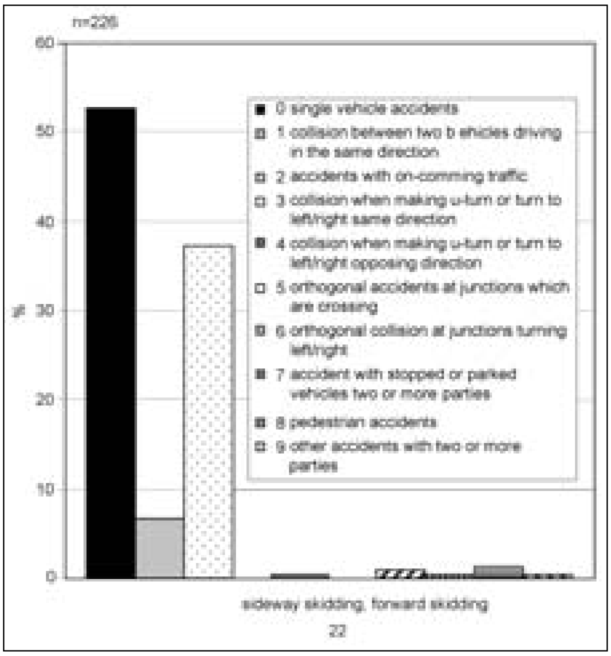


Figure 4: Vehicles sideway and forward skidding in Austrian accident main categories

To be in line with CARE main group C – “single vehicle accidents” - Austrian accident type 0 – “single vehicle accidents” were examined in more detail. Among 119 accidents 73% could be identified as passenger cars (87 cases). Analyzing the accident location more than 35% occurred in bends. Considering all criterions and on-scene material in a satisfactory quality required for reconstruction nine single vehicle accidents could be added to the study.

It needs to be mentioned that during the PENDANT project the work for ZEDATU was in progress too and not all single vehicle accidents were collected.

Categorization of single vehicle accidents

The accidents caused by a chain of circumstances were categorized regarding street section into bends or straight roads (Figure 5). In a second level the vehicle started skidding due to unadjusted speed and/or slippery surface and intervention by the driver could not stabilize the car anymore. It was also seen that drivers tried to avoid leaving the road to the side or a collision with an obstacle on the road by turning the wheel excessively. Within this type of accidents the vehicle started skidding after the collision-avoiding manoeuvre or it was possible to counter steer certain times but resulted in an accident anyway.

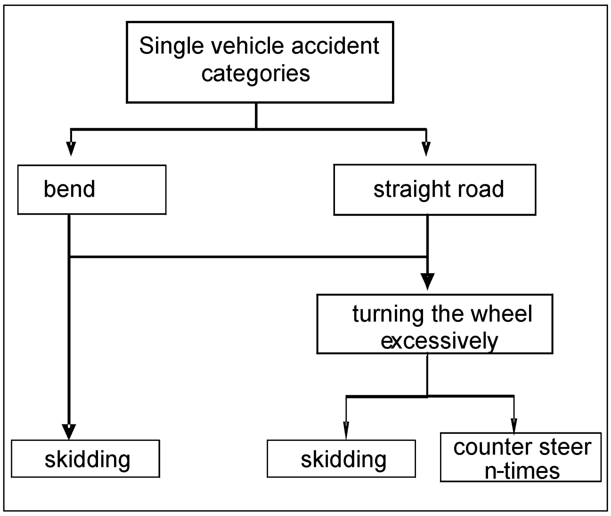


Figure 5: Single vehicle accident categories

Reconstruction of single vehicle accidents

Due to the fact more and more vehicles are equipped with ESP it was necessary to develop a tool simulating ESP in a numerical environment. ESP has a huge complex influence on vehicle dynamics and only a tool in an accident reconstruction software guarantees accurate reconstruction results. Besides Anti Lock Braking System Electronic Stability Program was implemented into PC Crash. Within the tool the yaw velocity is controlled. Based on the driven velocity of the vehicle and the actual steering angle required yaw velocity is calculated and is compared with the current existing yaw velocity. If predefined thresholds are exceeded the program intervenes by braking wheels separately depending on over or under steer.

For reconstruction of the single vehicle accidents involving vehicles equipped with ESP the following assumptions were made:

- identical vehicle path for both reconstructions (first without and second with ESP),
- equal sequences duration,
- equal braking pedal position.

Of course that will not fully match with accident reality but otherwise it gets very difficult to estimate behaviour of drivers.

Results

26 single vehicle accidents could be identified with 13 occurring in bends and another 13 taking place

Figure 6: Single vehicle accidents

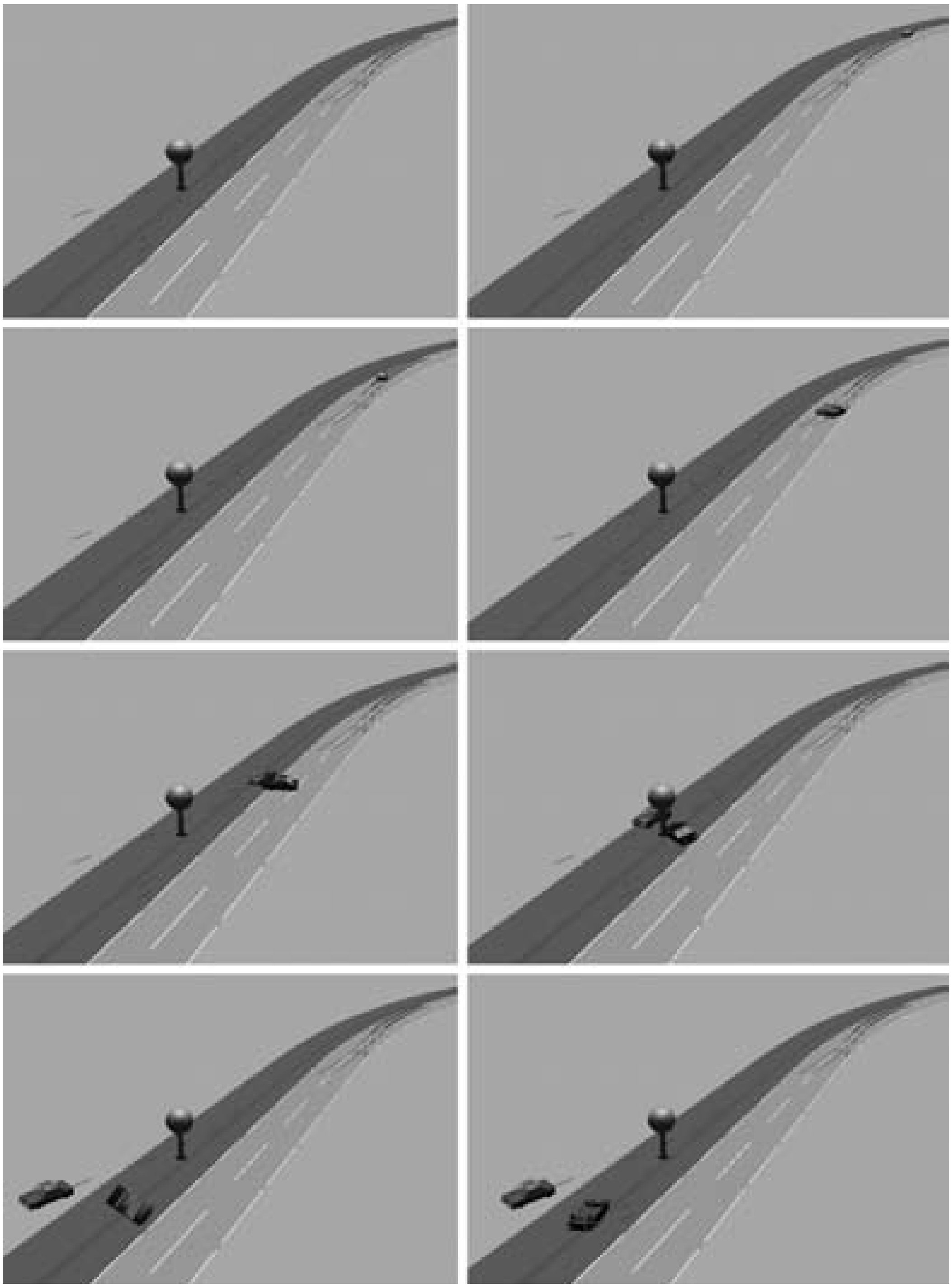


Figure 7: Single vehicle accident with 1s time sequence

on straight road sections (Table 1). Vehicles leaving the road and the wheels got stuck whilst skidding all of those resulted in a rollover (Figure 9), no matter if the accident occurred in a bend or on a straight road section.

road type	turning the wheel excessively	skidding	counter steer 3x	counter steer 2x	counter steer 1x	
bend	no	4				5
	yes	4	1		3	8
bend		8	1		4	13
straight road	no	1				1
	yes	5	1	1	5	12
straight road		6	1	1	5	13
		14	2	1	9	26

Table 1: Accident sequences

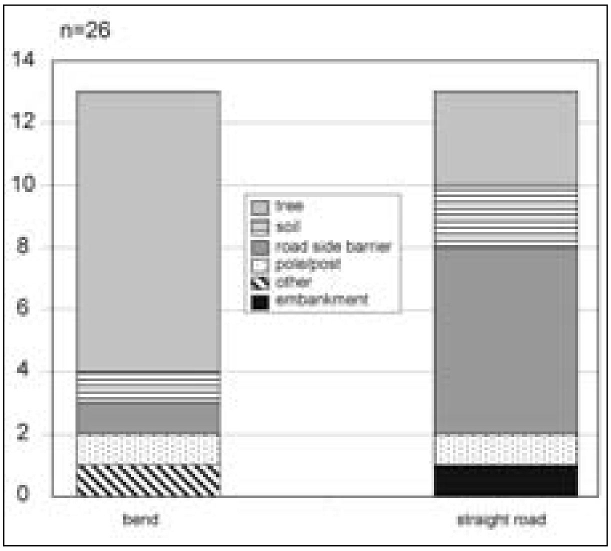


Figure 8: Collision partner of single vehicle accidents

In the example shown in Figure 6 a vehicle was leaving the road to the right into the verge. The driver turned the steering wheel sharply to stay on the road but got to the on-coming traffic road side. As he counter steered the yaw angle was exceeding the limit and the vehicle started to skid. At this point the vehicle approached the road, hit a tree and additionally the wheels got stuck at the soil. The accident resulted in a rollover. This single vehicle accident was reconstructed with PC-Crash. Assuming that the car was equipped with ESP the accident would have been prevented. However, depending on the road side infrastructure a frontal accident may have occurred.

The sequence in Figure 7 shows the movement in a perspective view at one second time step. Red coloured vehicle was equipped with ESP.

Single vehicle accidents in bends resulted mainly in collision with trees and poles/posts. In comparison most collisions happened on straight roads with road side barriers. No distinction within the type of barriers can be made in the database. Three of the single vehicle accidents on straight roads resulted in an impact with a tree and a further two got stuck in the soil whereby a rollover followed.

Figure 9 illustrates rollover regarding road category. It can be seen that rollovers occurred mostly when the wheels got stuck in the soil. Some single vehicle accidents resulted in a rollover in the category "impact". Three rollover accidents occurred in bends after an impact, one single vehicle accident had a rollover before a contact occurred and for another one a rollover happened without a collision. On straight roads one single vehicle accident had a contact before the rollover happened and for three cases no collision arose.

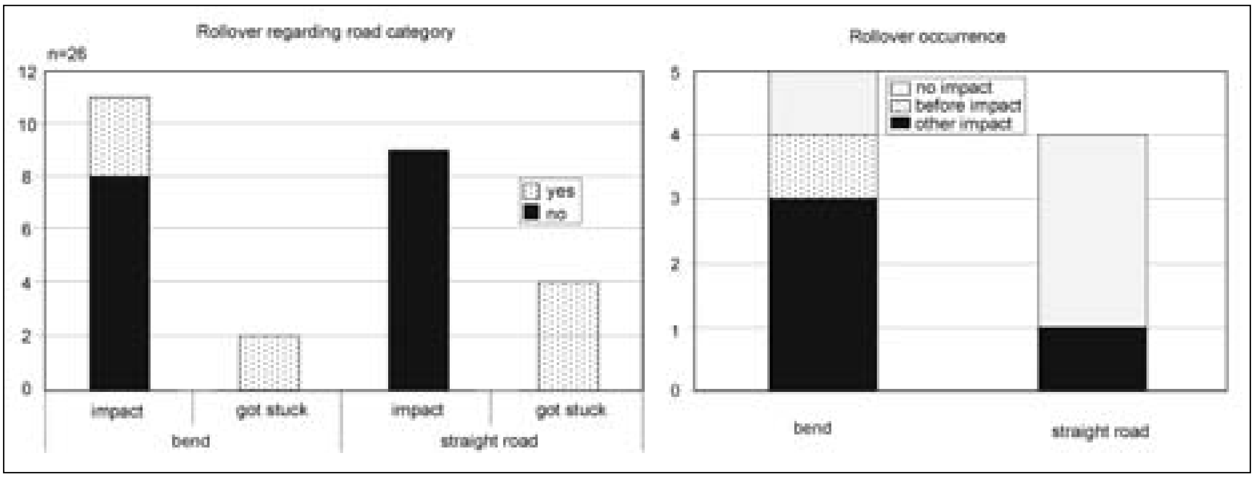


Figure 9: Rollover and road category

In bends four cases could have been avoided and on straight roads ESP would have prevented an accident in four cases. If it was not possible to avert the accident ESP led to a different impact configuration or crash severity was decreased. Delta-V as an injury severity parameter was reduced significantly due to ESP. To summarize up to 30% (eight of 26) of single vehicle accidents would have been prevented if the vehicle were fitted with ESP. Even if only a low portion of single vehicle accidents were available for investigation a good agreement can be seen with AGA and OKADA [6]. They found out a reduction of approximately 35% in single-car accidents. LANGWIEDER et al. [7] expect that ESP would be beneficial in at least 60% of the skidding related car accidents. ESP could have a probable or definite influence in about 34% of fatal accidents and 18% of injury accidents (SFERCO et al.) [8]. TINGVALL et al. [9] pointed out that on all road surfaces and in all accidents except rear-end impacts, the effectiveness of ESP is 22.1%.

For accidents which could not be prevented ESP led at least to another impact configuration. Tables 2 and 3 provide an impression of certain parameters of reconstructed single vehicle accidents. Table 2 explains those accidents which were not avoided or led to different impact configuration respectively. Table 3 shows the cases which could be prevented by ESP.

Following abbreviations were used in the next two Tables:

n/a not applicable
ai after impact
bi before impact
ni no impact

without ESP						with ESP			
impact location	PDoF	speed limit [kph]	rollover	Delta-V [kph]	occured	impact location	PDoF	Delta -V [kph]	rollover
F	01	50	no	11	n/a	R	02	5	no
F	01	70	yes	44	ai	L	11	15	no
F	11	130	no	27	n/a	L	10	9	no
F	01	130	no	40	n/a	L	09	4	no
L	08	70	yes	20	ai	F	12	52	no
L	10	100	no	37	n/a	L	10	4	no
L	08	130	no	74	n/a	L	08	64	no
L	11	999	no	58	n/a	L	10	8	no
R	02	50	no	29	n/a	R	01	8	no
R	02	70	no	49	n/a	F	01	70	no
R	12	80	no	49	n/a	F	12	70	no
R	02	100	no	57	n/a	F	01	67	no
R	01	100	no	66	n/a	R	02	5	no
R	08	100	no	66	n/a	R	02	6	no
R	07	999	no	39	n/a	F	01	23	no
T	03	50	yes	20	bi	F	12	50	no
T	00	70	yes	n/a	ni	M	00	n/a	yes
T	00	100	yes	n/a	ni	M	00	n/a	yes

Table 2: Single vehicle accidents which could not be avoided by ESP

without ESP						with ESP			
impact location	PDoF	speed limit	rollover	Delta-V [kph]	occured	impact location	PDoF	Delta-V [kph]	rollover
F	01	120	no	51	n/a	Prevented by ESP			
L	10	50	yes	22	ai				
L	11	70	no	8	n/a				
L	02	100	no	55	n/a				
R	11	80	yes	7	ai				
R	08	100	no	32	n/a				
T	00	100	yes	n/a	ni				
T	00	130	yes	n/a	ni				

Table 3: Prevented single vehicle accidents by ESP

Table 4 provides impact location and injury severity regarding Delta-V. On the left hand side vehicles are reported which were not equipped with ESP. Delta-V and injury severity were identified from database whereby injuries were assessed in hospital or from medical doctors. Frontal impacts led to side impacts whereby change of velocity Delta-V decreased as well as impact velocity. Accidents which could not be prevented and had side impact configuration resulted mainly in side impacts with a lower change of velocity Delta-V. In some cases side impacts developed with ESP in frontal collisions. Accidents in which the wheels got stuck at the soil ESP was not able to avoid a rollover.

without ESP			with ESP							
impact location	Delta-V [kph]	MAIS hospital	impact location	Delta-V [kph]	injury severity probability [%]					
					MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	MAIS 6
F	11	3	R	5	86	0	0	0	5	9
F	44	1	L	15	66	20	7	0	0	7
F	27	1	L	9	79	11	5	0	5	0
F	40	2	L	4	86	0	0	0	5	9
L	58	1	L	8	79	11	5	0	5	0
L	20	1	F	52	30	40	30	0	0	0
L	37	1	L	4	86	0	0	0	5	9
L	74	999	L	64	100	0	0	0	0	0
R	57	1	F	67	33	33	0	0	33	0
R	66	2	R	5	86	0	0	0	5	9
R	49	2	F	70	33	33	0	0	33	0
R	66	4	R	6	79	11	5	0	5	0
R	49	2	F	70	33	33	0	0	33	0
R	39	999	F	23	82	8	8	0	2	0
R	29	3	R	8	79	11	5	0	5	0
T	20	1	F	50	56	33	11	0	0	0
T	n/a	1	M	0	n/a	n/a	n/a	n/a	n/a	n/a
T	n/a	3	M	0	n/a	n/a	n/a	n/a	n/a	n/a

Table 4: Impact configuration and injury severity

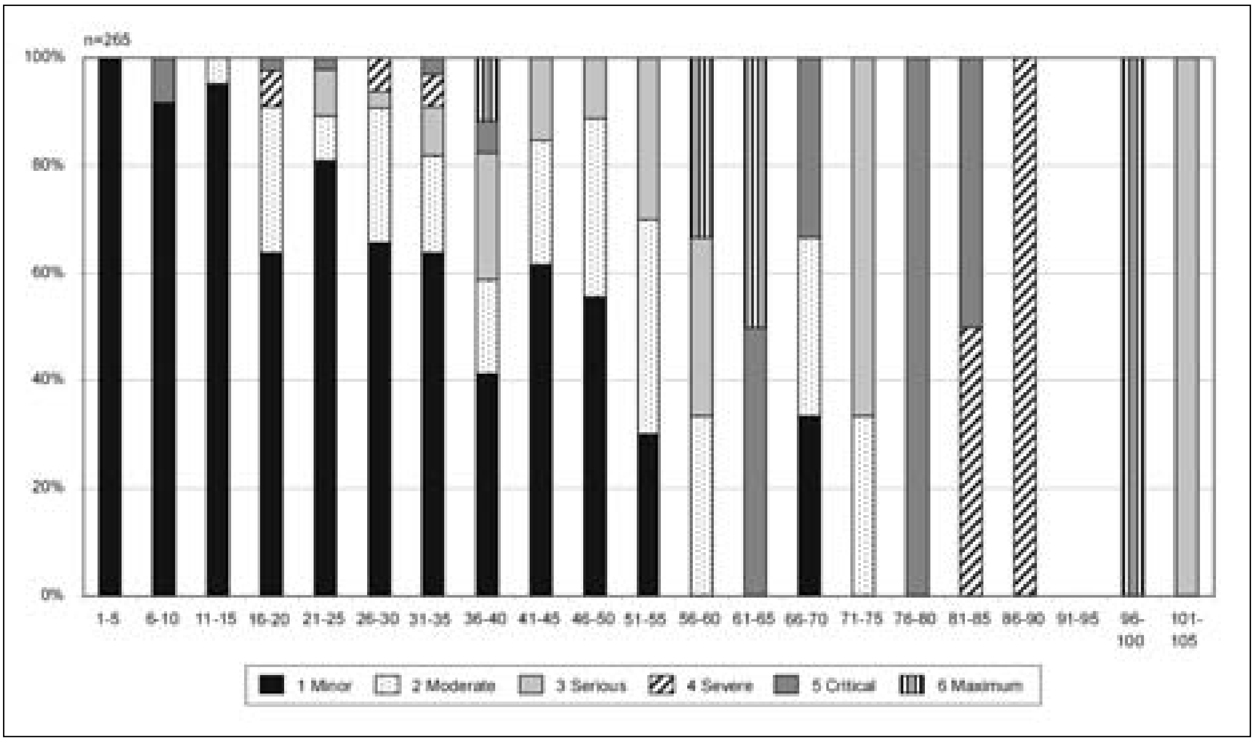


Figure 10: Injury severity of frontal accidents in PENDANT

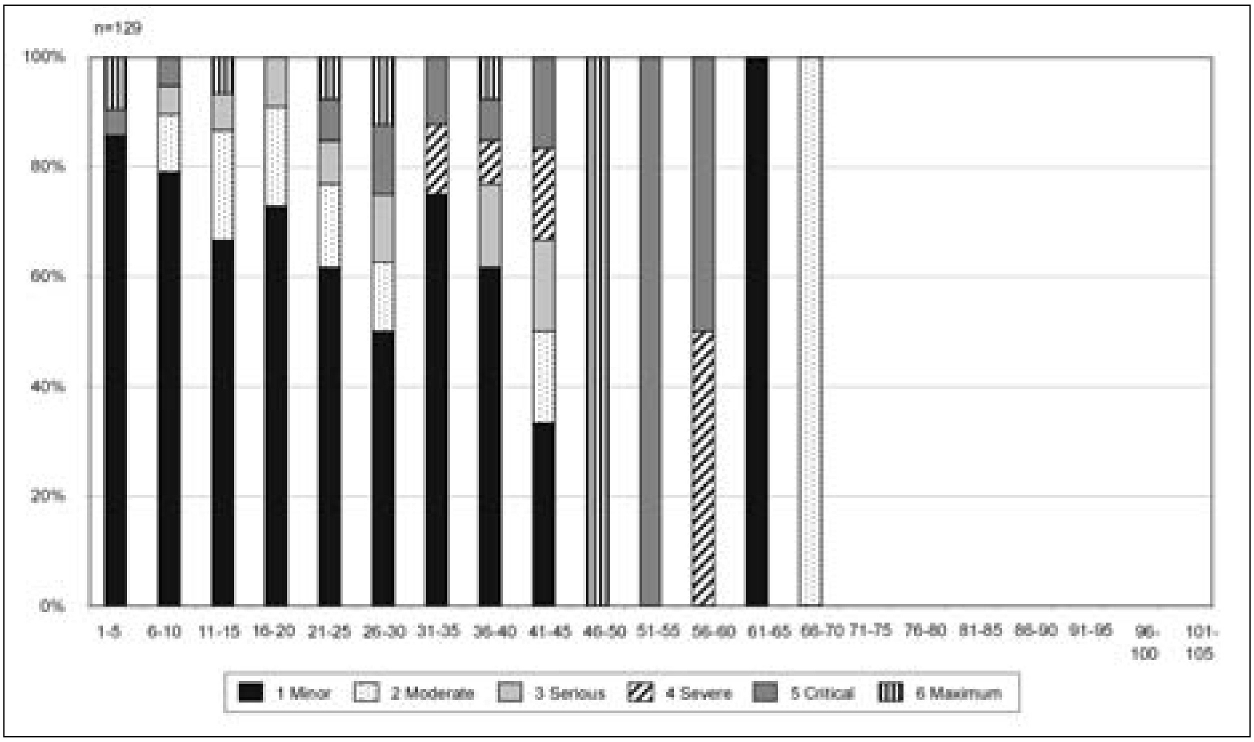


Figure 11: Injury severity of side impacted vehicles in PENDANT

Right handed side of the table provides impact location, Delta-V and injury severity probability of vehicles equipped with ESP in single vehicle accidents. Injury severity was estimated from frontal (Figure 10) and side impacted vehicles (Figure 11). Even if two databases were mixed injury severity was taken from PENDANT. ZEDATU is focussed on fatalities and it did not sound reasonable to investigate injury severity in this database. An analysis had been performed on single vehicle accidents only but the low portion of cases did not yield in satisfactorily results. Of course Delta-V is not sufficient enough and other aspects are responsible for injuries too. This could be seen especially for low values of Delta-V resulting in severe injuries.

Discussion

Even if a huge number of single vehicle accidents were available in the database only a few numbers were meeting all requirements needed for this detailed study. As it was figured out in general collection of on-scene material was not done by partners neither it was for the pre-collision phase. Especially references to skid marks, contact evidence with road side objects or throwing range of broken glass are essential. Merely Germany provided accidents from the GIDAS [11] database to PENDANT and scene sketches were investigated as a standard procedure. Besides of Germany only Sweden, the Netherlands and Austria provided single vehicle accidents with desired on-scene material. Sweden collected on-scene data for a different project whereby those accidents were used for PENDANT, too. Database ZEDATU increased the number of single vehicle accidents.

Conclusion

Single vehicle accidents can be divided into certain levels. The first level is based on infrastructure namely bends and straight road sections. In a second step the drivers could intervene by turning the steering wheel extensively to avoid a collision with obstacles or other hazards. Finally it was seen that the drivers could counter steer certain times before the yaw angle exceeded thresholds.

Though the sample was very small a good agreement with other studies is given. Roughly 30% of single vehicle accidents could be prevented by ESP. ESP led to different impact configuration when the accident was unavoidable.

Important aspects in accident investigation and reconstruction are pre-impact phases especially for single vehicle accidents. Most single vehicle accidents last some seconds before resulting in an impact or rollover. During this phase the drivers mainly try to avoid an accident. Essential for such reconstruction activities are scaled sketches from accident scene with traces from braking or skidding. Therefore it is concluded that PENDANT cannot be used for pre-collision investigation – primary (active) safety aspects.

In principle countermeasures can be developed at human (H) and vehicle (V) or infrastructure (I) level. This study covered vehicle level. As for further investigations roadside design and infrastructure needs to be addressed and implemented in a comprehensive in-depth database which can support legislation at HVI level.

References

[1] F. APARICIO on behalf of EEVC WG19: EEVC WG19 Activities on primary and secondary safety interaction; Paper Number 05-0462

[2] http://magpie.lboro.ac.uk/dspace/bitstream/2134/754/1/AR1886+Stairs+final+report.pdf

[3] http://www.vsi.tugraz.at/pendant/

[4] PENDANT: Description of Work; Proposal number: GMA2-2001-52066

[5] http://ec.europa.eu/transport/care/

[6] AGA and OKADA (2003): Analysis of vehicle stability control (VSC)s effectiveness from accident data. Paper no. 541, Proceedings of the 18th International technical Conference on the Enhanced Safety of Vehicles. NHTSA, Washington DC

[7] K. LANGWIEDER, J. GWEHENBERGER, TH. HUMMEL, J. BENDE: Benefit potential of ESP in real accident situations involving cars and trucks; GDV Institute for Vehicle Safety, Munich Germany; Paper Number 150

[8] R. SFERCO, Y. PAGE, J. Le COZ, P. FAY (2001): Potential effectiveness of the electronic stability programs (ESP) – what European field studies tell us. 17th International Technical Conference on the Enhanced Safety of Vehicles. Paper 2001.S2 – 0 – 327, June 4-7, 2001

[9] C.I. TINGVALL, M. KRAFFT, A. KULLGREN, A. LIE (2004): The effectiveness of ESP (electronic stability programme) in reducing real life accidents. Swedish National Road Administration, paper number 261. Traffic Injury Prevention, vol. 5, pp. 37–41

[10] PENDANT Deliverable D2 – Forms and Glossary

[11] http://www.gidas.org/

[12] PENDANT Deliverable D8 – Harmonised analytic methods to predict casualty reductions of both accident and injury reduction measures

D. Patel, M. Ross
Physics Department, University of Michigan, Ann Arbor, USA

C. Compton
University of Michigan Transportation Research Institute, Ann Arbor, USA

T. Wenzel
Lawrence Berkeley National Laboratory, Berkeley, USA

Intrusion and the Aggressivity of Light Duty Trucks in Side Impact Crashes

Abstract

The increase in light duty trucks (LDT) on the road in the US is a safety concern because of their aggressivity, or risk they present to occupants of cars, especially in side impacts. We use FARS data to look at fatality trends in frontal and side impacts between cars and LDT. FARS data is also used to determine risk, or fatalities per registered vehicle, imposed on car drivers from other vehicle types. We use NASS CDS data to investigate sources of serious injuries in vehicles with side impact. These sources of injury are categorized into three major groups: 1) contact without intrusion, 2) contact with intrusion, and 3) restraints. We find a greater fraction of intrusion related injuries in cars struck on their side by SUV or pick-up trucks than when they are struck by other cars.

Introduction

Over the past 25 years in the US, the number of driver deaths from side impact collisions has increased nearly 40%, while driver deaths from frontal collisions have decreased by about 20% (shown in Figure 1). This trend can partly be explained by the increasing presence of light duty trucks (LDT) on the road, primarily sport utility vehicles (SUV) and pick-up trucks (PU). In 1980 less than 20% of new vehicles sales were LDT, and currently about half of new vehicles sold in the U.S. are LDT (EPA 2005). The stiffness, frontal height and structure of SUV and PU make them especially dangerous to car occupants in near side crashes, in which the front of an SUV or PU impacts the side of the car. Research on vehicle incompatibility has primarily concentrated on frontal crashes between cars and LDT, with a few papers focusing on side impacts (SIEGEL 2001, ACIERNO 2004, and GABLER 2003). The lack of crush space available between an occupant and the impact point in a near side crash makes it difficult to design cars to

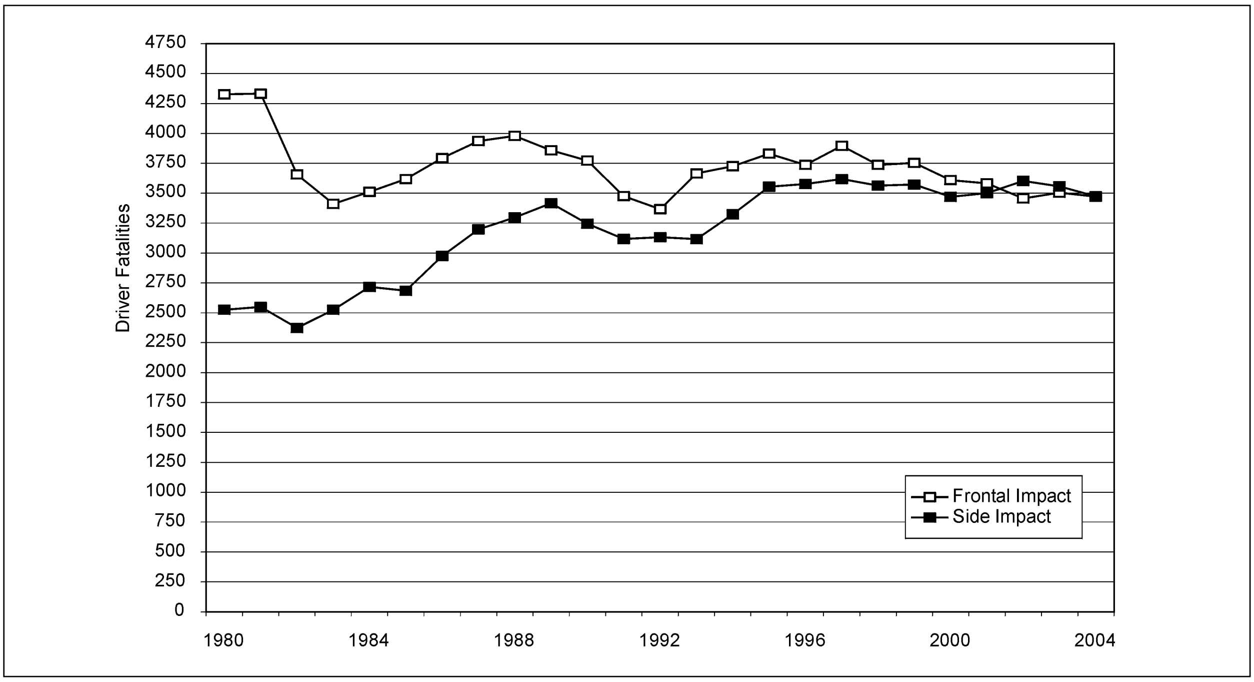


Figure 1: US driver fatalities in frontal and left side impact collisions. FARS 1980-2004

better protect their occupants. Figure 2 shows a substantial decrease in driver fatalities in car-car frontal crashes, where there is more room and structure to work with to protect occupants. Over this period, the number of cars on the road has been gradually increasing, so this decrease indicates actual safety improvements in car design and perhaps also road design.

As shown in Figure 2, driver fatalities in car-LDT side crashes have more than doubled since 1980, while a more modest increase is seen in car-LDT frontal crashes. Among car-LDT collisions, driver fatalities in side impacts exceeded the number of frontal collisions by the mid 1990s. This did not happen with either car-car or LDT-LDT collisions.

In this paper we use fatality and registration data to look at risk in cars hit on their side by other vehicles in two-vehicle crashes. We use in-depth accident investigation data to analyze the source of severe injuries in vehicles hit in side impacts and compare it to vehicles with frontal impacts. The role of intrusion is examined in these cases, including its dependence on the type of bullet, or striking, vehicle. Finally we examine the body region injured in cars hit on the driver's side by the type of bullet vehicle.

Data Sources

The two US databases used in this study are the Fatality Analysis Reporting System (FARS) and the National Automotive Sampling System Crashworthiness Data Systems (NASS CDS). FARS is a census of all motor vehicle collisions involving a death within 30 days. All of the information contained in FARS is based solely on a police accident report.

NASS CDS involves in-depth investigation of crashes, fatal and nonfatal. It contains a sample of about 5,000 police reported crashes each year, involving at least one tow-away light duty vehicle. Selection preference is given to cases with newer model year vehicles and occupants with higher severity injuries. Detailed information on all occupant injuries is obtained from medical records and interviews, and includes an Abbreviated Injury Scale (AIS) score. AIS is a system of ranking injury severity, based on threat to life, from 1 (minor injury) to 6 (maximum). Crash-investigators examine the crash scene and vehicle(s) and record vehicle damage including external crush and internal intrusion measurements. This crash investigation may take place weeks or even months after the

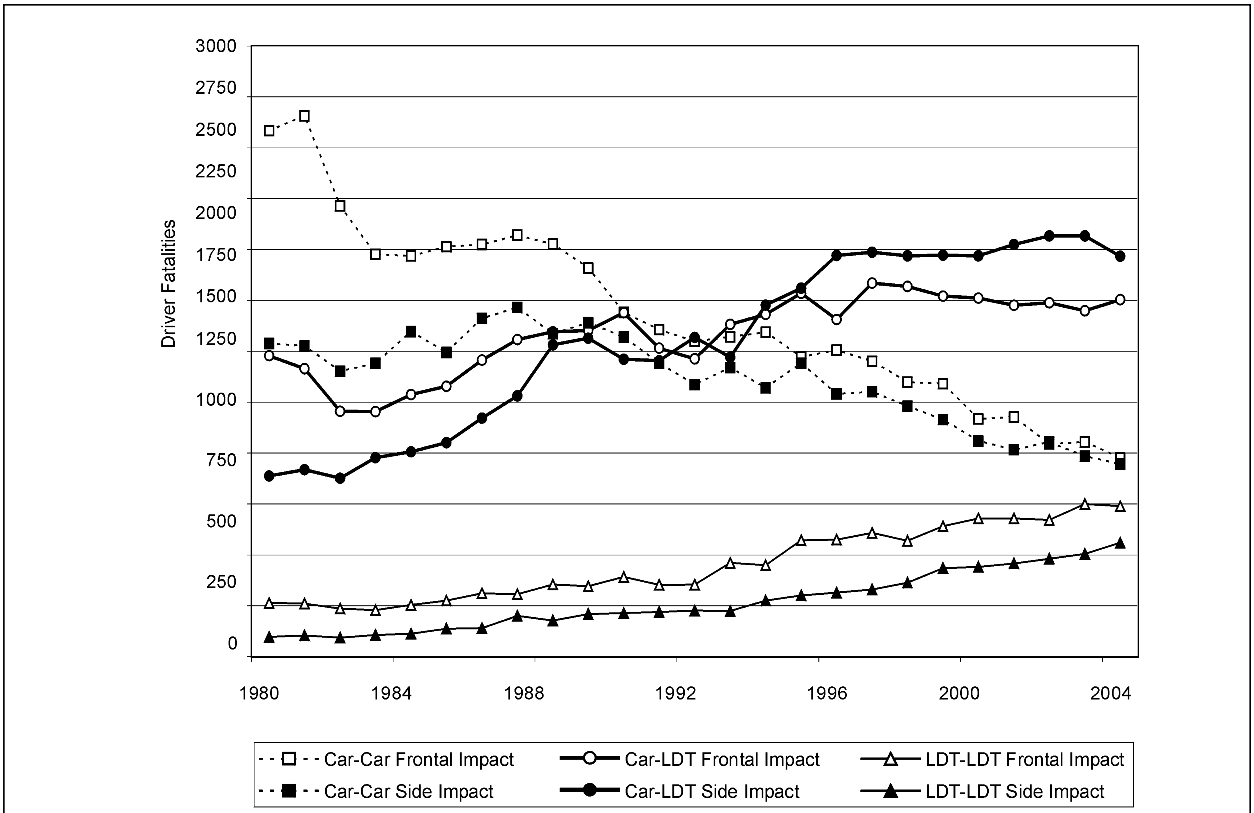


Figure 2: US driver fatalities in frontal and side impact collisions, by vehicle type. FARS 1980-2004

crash occurred. Each injury is coded to an area of the vehicle ascribed to be its source. For this study, we only list sources of injuries that have a confidence level of “certain” or “probable”. In about 10% of high severity (AIS 3-4) injuries, the source is unknown or has only a “possible” confidence level.

There are a number of different ways of counting the NASS CDS data. Each case has an accident file, vehicle files, and occupant files. Data can be counted in terms of number of collisions, number of vehicles, number of occupants injured, or number of injuries sustained. For this study, which is focused on injury causation and source, we look at the number of serious (AIS 3-6) injuries sustained by the drivers of light duty vehicles in particular crash types (frontal, side impact, one-vehicle, and two-vehicle). Drivers involved in severe collisions tend to have more than one serious injury. In an effort to reduce any double counting, we count multiple injuries to the same AIS90 body region attributed to the same source on the vehicle, as one injury. This reduces the number of injuries per driver to an average of about 1.5.

Each case in NASS CDS is assigned a weighting factor, which is claimed to be an estimate of the number of similar crashes occurring in the US that year that have not been sampled. Crashes with high severity injuries (AIS 4-6) typically have a weight of about 50, meaning that NASS CDS samples about 1 in 50 serious injury collisions. In this paper we present the “raw data”, meaning the actual number of cases investigated, as well as the “weighted data”, meaning the cases multiplied by their weighting factor. We use a cap of 500 for the weighting factor, so any cases with weights greater than 500 are set to 500. This is to ensure that extremely large weighting factors on a few cases do not skew the results. Only 1 percent of cases had weights larger than 500.

In the following analysis using NASS CDS data, we confine our study to belted drivers in vehicles model year (MY) 1997 or newer, and crash years 1997 through 2004. The bullet vehicles can be any MY. We do not include any crashes involving rollover, since the injury mechanisms for rollover are quite different than for other types of crashes. NASS CDS contains a Collision Deformation Classification (CDC) for each damaged area on the vehicle. The damaged area coded as the primary CDC is, in the investigator’s judgment, the worst damage or injury producing event, with injury taking precedence. We use the primary CDC to determine if the vehicle had a frontal or side impact.

Results

Vehicle structure

The limited amount of space between an occupant and the outer surface of the vehicle in a side impact leaves occupants more vulnerable than a head-on collision with similar severity. There is little crush space for energy absorbing structures to deform without intruding into the occupant space. Ideally, the side structure of the struck vehicle should be stiffer than the front structure of bullet vehicle, permitting the front of the bullet vehicle to absorb most of the crash energy while keeping the passenger compartments intact. Figure 3 shows the risk to car drivers when hit on the left side (8-10 o’clock) by different types of bullet vehicles. Risk here is defined as car driver deaths per million registered bullet vehicles by type. The risk from different sizes of bullet cars is roughly the same, but SUV and PU are 2 to 6 times as risky as cars are [Using fatalities per police reported crash as risk, GABLER found SUV and PU to be 5 to 7 times as risky as other cars (GABLER 2003).]. This suggests that in near-side collisions, mass is a relatively unimportant safety factor compared to the structure and stiffness of the front of the bullet vehicle. Most SUV and PU are built body-on-frame, in which the separately built passenger cabin and cargo bed are attached to a stiff chassis, causing the fronts to be very stiff and structurally inhomogeneous. This leads to less structural interaction with the opposing vehicle and more chance of intrusion into the

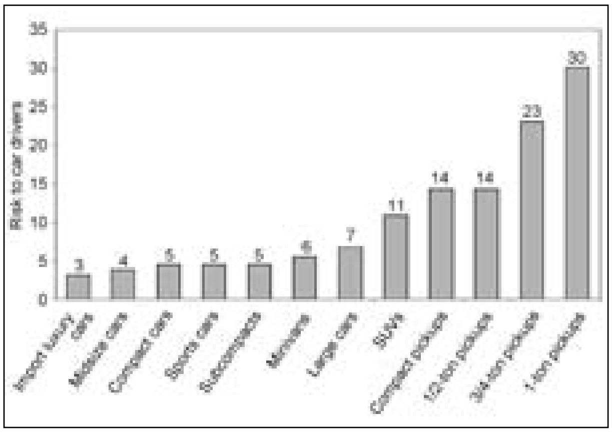


Figure 3: Risk to drivers of cars struck on the left side by other vehicles. Risk is fatalities per million registered bullet vehicle. Target car is MY 2000+. FARS and Polk data 2000-2004

opposing vehicle's passenger compartment. Their frontal height is also dangerous, especially in side impacts, since it is much higher than the door sill of a car. Using a sample of vehicle involved in side impact crashes, SIEGEL et al. find the average difference in heights of SUV/PU bumpers to the car frames is 5.7 inches (SIEGEL 2001). Because SUV and PU are structurally quite different from vans and minivans, and because the amount of NASS CDS data available on vans and minivans is so small, we leave them out of the following analysis and group together SUV and PU. Car-based or unit-body SUV have recently been adopted in some popular models, but they have relatively little influence on the data through 2004.

Causes of injury

When a vehicle crashes, one way occupants can be injured is through hard contact with an interior surface of the vehicle. This can happen, for example, if the occupant is not properly restrained or if the restraints fail to hold the occupant in position, as in side impacts where seat-belts often fail to restrain the occupant laterally. Contact with an interior surface can also occur when that surface has intruded into the passenger compartment, encroaching on the occupant's survival space. Even if there is no intrusion and the restraints prevent any hard contact, an occupant can still sustain injuries if the overall center of mass acceleration of the vehicle is too high. In these types of injuries, the restraints themselves may be listed as the source of injury. Table 1 shows these three main categories: 1) contact – non intrusion, 2) contact – intrusion, and 3) restraints, for vehicles with front damage and side damage. We only consider non-rollover crashes in the following tables.

Table 1 contrasts the main sources of injury to drivers of light duty vehicles with front damage and with side damage. Contact with intruded components is more prevalent in side (61%) than frontal impacts (35%). Restraints constitute a larger fraction of injury sources in vehicles with front (16%) versus side (4%) damage (raw data). In the case of front damage, half of injuries are associated with the steering wheel, knee bolster, or instrument panel. In side impacts, these sources account for only 6% of injuries. In vehicles with left side damage 72% of injuries are attributed to the left side, which includes the door interior and the A and B pillars; of these injuries 79% are intrusion related.

		Vehicle has front damage						Vehicle has side damage					
		Raw			Weighted			Raw			Weighted		
		Injuries	% of total		Injuries	% of total		Injuries	% of total		Injuries	% of total	
Contact – non intrusion	Front interior*	173	28%	42%	14064	31%	44%	19	4%	25%	1123	4%	24%
	Left side**	39	6%		1327	3%		65	15%		3865	15%	
	Floor	38	6%		2702	6%		15	3%		581	2%	
	Roof	9	1%		1878	4%		8	2%		422	2%	
Contact – intrusion	Front interior*	155	25%	35%	7905	17%	25%	8	2%	61%	479	2%	57%
	Left side**	17	3%		727	2%		243	57%		13591	54%	
	Floor	34	5%		2248	5%		2	0%		38	0%	
	Roof	9	1%		414	1%		8	2%		71	0%	
Restraints		102	16%		11338	25%		18	4%		2937	12%	
Other***		44	7%		2696	6%		43	10%		1850	7%	
Total		620	100%		45299	100%		429	100%		24957	100%	

* Includes steering wheel, instrument panel, knee bolster, and windshield

** Includes left side interior, A and B pillars, and left window

*** Includes fire, other occupants, loose objects, and exterior of vehicle

Table 1: Source of driver injuries. AIS 3-6 injuries in vehicles MY 1997+, non-rollover. NASS CDS 1997-2004

Intrusion

Table 2 shows the percentages of injuries coded to a component that intruded 15cm or more, in cars with front and side damage. In cars with front damage there is little difference in the fraction of intrusion related injuries resulting from other cars compared to SUV or PU (18%, 19%). However, there are significantly more intrusion injuries in left side impacts, especially when the bullet vehicle is an SUV or PU (58%) then when it is another car (35%). Intrusion injuries are 1.7 to 2.5 times more prevalent in cars hit in side impacts by an SUV or PU than by another car.

Body region

Table 3 shows body regions of car drivers injured when struck by other cars or SUV/PU, in the case of two-vehicle collisions, or in one-vehicle crashes. Cars struck by an SUV or PU are associated with more head injuries (17%) than cars struck by another car (10%), while cars struck by another car have a greater fraction of lower extremity (i.e. leg) injuries than cars struck by an SUV or PU. This result is in general agreement with the study done by SIEGEL et al. using CIREN data (SIEGEL 2001). This pattern is possibly due to the greater frontal height of the striking SUV or PU.

	bullet vehicle type			
	raw data		weighted data	
	car	SUV or PU	car	SUV or PU
Target=car with front impact (209 injuries)	18%	19%	17%	13%
Target=car with left impact (188 injuries)	35%	58%	21%	53%

Table 2: Percent of injuries associated with an intrusion. AIS 3-6 driver injuries resulting from an intrusion >15cm, listed by other vehicle type. Target vehicle is a MY 1997+ car, non-rollover. NASS CDS 1997-2004

Table 3 includes the data for cars involved in side impact one-vehicle non-rollover crashes for comparison. These crashes also cause more head injuries and less lower extremity injuries than car-car crashes, but unlike car-SUV/PU crashes they cause less thorax injuries. Note that the small sample sizes (92 car-car injures, 103 car-SUV injuries, and 116 one vehicle crashes) indicate a large amount of statistical error here.

Conclusions

Using NASS CDS data we have shown the distribution of injury sources in vehicles with side and front damage. In vehicles with front damage the sources are primarily steering wheel, knee bolster, floor and restraints. While in vehicles with side damage nearly three quarters of serious injuries come from contact with the left side interior and B pillar. Restraints play a smaller role in side impacts compared to frontal impacts. This may be an indication that seat-belts are not very effective in side impacts or that the overall center of mass acceleration is typically not high in these crashes. This may also imply that injuries resulting from side impacts are not sensitive to vehicle mass. It is clear that intrusion plays a major role in injury causation in side impacts. SUV and PU cause 20% to 30% more intrusion injuries to car drivers in side impacts than other cars do. This is likely due to the front structure of SUV and PU being too high to effectively interact with the car's frame upon impact, and the overly stiff frame rails concentrating the

	Raw data			Weighted data		
	2 vehicle crashes-bullet vehicle type		1 vehicle crashes	2 vehicle crashes-bullet vehicle type		1 vehicle crashes
Body Region	Car	SUV or PU		Car	SUV or PU	
Head	10%	17%	24%	6%	21%	19%
Face	0%	3%	1%	0%	1%	0%
Thorax	40%	45%	29%	31%	41%	26%
Abdomen	5%	10%	9%	3%	9%	9%
Spine	1%	2%	7%	1%	1%	14%
Upper Extremity	8%	4%	7%	29%	2%	9%
Lower Extremity	36%	20%	23%	30%	25%	23%
Total	100%	100%	100%	100%	100%	100%
Number of injuries	92	103	116			

Table 3: Distribution of driver injuries in side impacts. AIS 3-6 driver injuries in a car (MY 1997+) with side damage, non-rollover. NASS CDS 1997-2004

force at potentially weak areas on the target car's door.

A look at the injured body regions shows that drivers of cars hit in the side by SUV or PU have a different distribution of injuries than those drivers hit by cars in side impacts. Head injuries are somewhat more prevalent in car-SUV/PU crashes while lower extremity injuries are more prevalent in car-car crashes.

Strengthening the sides of vehicles with more rigid materials will probably reduce the number of intrusion related injuries. As pointed out by AUGENSTEIN et al., more rigid materials will limit energy absorption in a crash, resulting in greater center of mass acceleration of the vehicle and therefore the occupant. This trade off may be acceptable for reducing side impact injuries since accelerations in side impacts may not be as high as in frontal, and because there is little crush space available on the side of the vehicle. Another way to decrease side impact injuries is to improve the fronts of the bullet vehicles. Car-based SUV are becoming more prevalent and are safer to car occupants because their fronts are better at absorbing energy and they do not have the stiff frame rails present in the body-on-frame SUV and PU.

References

[1] J.H. SIEGEL et al.: Factors Influencing the Patterns of Injuries and Outcomes in Car versus Car Crashes Compared to Sport Utility, Van, or Pick-up Truck Versus Car Crashes, J. Trauma 51 (5) 975-990 (2001)

[2] S. ACIERNO et al.: Vehicle Mismatch: Injury Patterns and Severity, Accid. Anal. and Prev. 36, 769-772 (2004)

[3] H.C. GABLER: The Evolution of Side Crash Compatibility between Cars, Light Trucks and Vans, SAE 2003-01-0899 (2003)

[4] A.F. TENCER et al.: Factors Affecting Pelvic and Thoracic Forces in Near-side Impact Crashes, Accid. Anal. and Prev. 37, 287-293 (2005)

[5] C.M. FARMER, E.R. Braver, E.L. MITTER: Two-Vehicle Side Impact Crashes: The Relationship of Vehicle and Crash Characteristics to Injury Severity, Accid. Anal. and Prev. 29 (3), 399-406 (1997)

[6] EPA: Light-Duty Automotive Technology and Fuel Economy Trends: 1975 through 2005 (2005)

[7] J. AUGENSTEIN et al.: The Role of Intrusion in Injury Causation in Frontal Crashes, SAE 2005-01-1376 (2005)

[8] M. ROSS, D. PATEL, T. WENZEL: Vehicle Design and the Physics of Traffic Safety, Physics Today, January 2006

Y. Page
Laboratoire d'Accidentologie, de Biomécanique et d'Études du Comportement humain PSA Peugeot Citroën Renault, France

P. Thomas, A. Kirk
Vehicle Safety Research Centre, University of Loughborough, UK

V. Hervé
Centre Européen d'Études de Sécurité et d'Analyse des Risques, France

The Effectiveness of Side Airbags in Preventing Thoracic Injuries in Europe

Abstract

During the last 5 years, the number of cars fitted with side airbags has dramatically increased. They are now standard equipment, even on many smaller cars or less luxurious vehicles. While some side airbags offer thoracic protection alone, there are those that combine thoracic and head protection (of which most deploy from the seat). Other systems employ separate airbags for head and thorax protection, which are designed to be effective noticeably in a crash against a pole.

This paper proposes an evaluation of the effectiveness of side airbags in preventing thoracic injuries to passenger car occupants involved in side crashes. First, the target population (who can take benefit of side airbag deployment and in what circumstances) is defined. Side airbags can be especially effective in cases of impacts on the door with intrusion at a certain impact speed. Then, an example case of a side impact with side airbag deployment is given were side airbag deployment is thought to have had a positive effect on injury outcome. A further case is presented where the impact configuration is likely to have reduced the effect of side airbag deployment on injury outcome. Finally, the estimation of side airbag effectiveness (in terms of additional occupant protection brought exclusively by the airbag) is proposed by comparing injury risk sustained by occupants in (more or less) similar cars (fitted or non fitted with airbags) because, during these years, car structure, and side airbag conception have considerably evolved.

In-depth accident data from France, the UK and Germany has been collected. Out of 2,035 side impact accident cases available in the databases, we selected 435 occupants of passenger cars (built from 1998 onwards) involved in an injury accident between year 1998 and year 2004 for EES (Energy Equivalent Speed) values between 20km/h and 50km/h. The occupants, belted or not, were sat on the struck side, whatever the obstacle and type of accidents (intersection, loss of control, etc.). For multiple impact crashes, the side impact is assumed to be the more severe one. Passenger cars were fitted with (96) or without (339) side airbags. Most of the potential risk explanatory variables were correctly and reliably reported in the databases (velocity – impact zone – impact angle – occupant characteristics, etc.).

The analysis compared injury risks for different levels of EES and different types of side airbags. A logistic regression model was also computed with injury variables (such as thoracic AIS 2+ or AIS 3+) as the dependant variable and other variables (including airbag type and EES) as explanatory injury risk factors.

Results revealed statistically non-significant reductions in thoracic AIS 2+ and AIS 3+ injury risk in side airbag equipped cars in the impact violence range selected (odds ratio between 0.84 and 0.98 depending on types of airbags).

The results are discussed. The non-significance is assumed to be due to a low number of cases. Statistical analysis for head injuries was not possible due to the low number of accident cases with passenger cars fitted with head airbags in the databases. Moreover, the discrepancies between the data coming from different countries (especially calculation of EES) might have introduced instability in the analysis.

Introduction

During the last 5 years, the number of cars fitted with side airbags has dramatically increased. This went with the new regulation governing design of vehicles for side impact crashes introduced in the European Union in 1996 (UNECE R95). They are now standard equipment, even on many smaller cars or less luxurious vehicles. While some side airbags offer thoracic protection alone, there are those that combine thoracic and head protection (of which most deploy from the seat). Other systems employ separate airbags for head and thorax protection which are designed to be effective, noticeably in a crash against a pole.

The effectiveness of side-mounted airbags in real-world accidents has already been studied a few times in the literature, though much later than frontal airbags. These studies followed biomechanical studies (experiments and numerical simulation) on side airbag effects, especially for out-of-position occupants and restrained children (e.g. PRASAD et al, 2001; TYLKO et al, 2001, SCHNEIDER et al., 2005, DALMOTAS et al., 2001). Evaluation studies started with anecdotal case studies and description of side crashes involving cars equipped with side airbags. For example, KIRK and MORRIS performed an interesting initial case review (47 UK cases) that details the conditions under which airbags might or might not be effective (KIRK and MORRIS, 2003). Each case with side airbag deployment was assessed to determine where deployment had no influence on occupant injuries (due to crash type or low crash severity); crash severity was too high to expect injury mitigation; deployment prevented injury; or where there was a possible causal relationship between the injuries to the adjacent occupant and deploying side airbag. However, some crashes were too complex to assess potential benefit. The study concluded that side bag deployments are preventing injuries in the real world. However, deployment is sometimes taking place in cases where it would not be expected (especially when the deployment is on the non struck side and in some frontal impacts). In some cases, the crash severity exceeds the protection capabilities of the airbag systems. On the other hand, a few cases presented injuries that might have not occurred without bags, so further consideration should be given to possible injury mechanisms.

Then, a series of real-world studies based on field accident data started. After BAUER et al. (BAUER et al., 2000), YOGANANDAN et al. analyzed field data on side impact injuries in vehicles equipped with side airbags (i.e. 68 cases with side airbag deployment in side crashes, drawn from the US National Accident Sampling System). They mainly described impact cases with variables such as occupant age, gender, height, weight, delta-V, injured body regions, number of injuries and injury severity. This preliminary study was followed by another one comparing head injury outcomes sustained by occupants involved in side impacts in cars, light trucks and vans equipped with or not equipped with side airbags (whatever types) in a matched-pair design (YOGANANDAN et al., 2005). Out of the 61 raw cases with side airbag deployments selected in the NASS files from 1994 onwards, only 23 had head injuries. Controls (same make model and year of the vehicle but without airbag) were only 17. Consequently, a case control analysis was not possible. The authors suggested that the separate system of torso and curtain side airbags appears to offer improved protection to the head though.

In this phase of side airbag effectiveness exploration, all authors underlined that findings based on small samples should be reinforced with additional data in the future.

Then evaluation studies turned towards the comparison of injury risk sustained by occupants involved in side crashes in cars fitted with side airbags versus cars without side airbags. In case of fitting, some studies distinguished torso airbags and head airbags and mounting locations (door, seat, cant rail). For example, McGWIN et al. analyzed 1997-2000 nearside impact data using US NASS data and concluded that front seat occupants of vehicles fitted with side airbags had a risk of injury similar to occupants of vehicles without side airbags (McGWIN et al., 2003). However, the authors combined cars fitted with side airbags as standard and as optional equipment and did not make any distinction between types of side airbags. This could have introduced a bias in the analysis.

MORRIS et al. used UK national accident files and also in-depth accident investigations to determine how injury outcomes have changed between cars manufactured pre 1993 and newer cars manufactured post 1998 (MORRIS et al., 2005). The results seem contradictory: seriously injured and killed rates for belted struck side front occupants are lower in newer cars compared to older but the rate of serious chest injury is higher in the sample of cars with side airbag deployment (25%) than the sample of cars with no side airbag deployment (10%). They then suggested good benefits from regulation in reducing struck side injury outcomes. Results about side airbag effectiveness based upon a sample of 287 occupants involved in struck-side crashes suggested that cant rail airbags would be effective in preventing serious head injuries, that door-mounted and seat-mounted airbags would not prevent AIS 2+ head injuries, that door-mounted airbags would reduce chest AIS 2+ injuries but that seat-mounted would not reduce AIS 2+ chest injuries. However, cars with side airbag deployment were compared to cars without side airbag deployment (including cars fitting with and cars not fitted with side airbags), which is suggesting a bias in crash severity in the two samples (crashes with no airbag deployment are less violent). These inconsistent findings led the authors suggesting that out-of-position occupants could play a role in the injury mechanisms, which should then be regarded carefully.

The only published paper, to our knowledge, studying the effectiveness of side airbags in preventing fatalities with an epidemiological design and statistical analysis is the one by BRAVER and KYRYCHENKO (2003) using data from the US General Estimates System and the Fatality Analysis System. This study computed the rate ratios for deaths per nearside collision for model years 1997-2002 during 1999-2001 for side airbags designed to reduce injuries to both torso and head and those designed only to prevent torso injuries. Weighting this data to a national level resulted in estimated 22,289 drivers in passenger cars with head /torso side airbags and further 45,640 with torso only side airbags fitted. Out of these, there were 35 near-side driver deaths in cars fitted with head/torso bags and further 105 when torso only bags were present. Results show a decrease in driver fatality risk in near-side crashes by 45% in passenger cars equipped with head-torso airbags and by 11% in cars fitted with torso airbags.

Finally, the last study available is the one by OTTE and RICHTER (2006). This study aimed at analyzing and comparing injury patterns of car occupants after side impacts in cars fitted or not fitted with side airbags. Out of 9,865 accident cases documented in the GIDAS database between 1999 and 2004, 71 concerned passenger car occupants involved in side crashes with side airbag deployment, seated on the impact side, and 266 concerned occupants involved in the same type of crash but without side airbag deployment. Delta-V in these crashes ranged from 5 to 50km/h. The analysis consisted of comparing the statistical distributions of a few parameters for both groups and to run a case by case complementary investigation. The authors observed some noticeable differences in the two groups (large cars are more likely to be equipped with side airbags, side impacts with deployment are more frequently located in the doors, delta-Vs are higher for cars with side airbags, the opponent is more frequently a passenger car for cars with side airbags). Consequently, the descriptive statistical analysis was not able to determine whether side airbags show a protective effect. This is also mainly due to the complexity of the types of crash under study. A multivariate analysis concluded with similar results. On the other hand, an in-depth case-by-case analysis based on statements made by an experienced accidentologist showed that in 40% of the deployed side airbag cases, the injury outcome would be possibly lesser than the one expected, taken into consideration the parameters of the crash and impact. The authors concluded that the protective effect of the side airbag is difficult to assess from the accident data. This is due to very different impact situations and very different relative movements of the car occupants. As a matter of fact, results coming out from statistical analysis and in-depth analysis seem to be contradictory.

This paper proposes an evaluation of the effectiveness of side airbags in preventing thoracic injuries to passenger car occupants involved in side crashes. First, the target population (who can take benefit of side airbag deployment and in what circumstances) is defined. Side airbags can be especially effective in cases of impacts on the door with intrusion at a certain impact speed. Two case examples illustrate how changes in crash configuration may have an influence on side airbag performance. Finally, the estimation of side airbag effectiveness (in terms of additional occupant protection brought exclusively by the airbag) is proposed by comparing injury risk sustained by occupants in (more or less) similar cars (fitted or non fitted with airbags) because, during these years, car structure, and side airbag conception have considerably evolved.

Method

Data sources

Three kinds of sources have been used:

- The French and the UK road injury accidents national census has provided an estimation of the population targeted by side airbags by counting the annual number of fatalities and seriously injured casualties as passenger car occupants in side impacts. Then the LAB in-depth accident database has been used in order to get the repartition of these casualties according to their location: impact nearside or far side. It is indeed assumed that airbag can protect from intrusion but cannot protect occupants located in the opposite side of the impact.

- Then, CCIS (Co-operative Crash Investigation Study) cases (UK) were used in order to conduct case analyses and further specify, amongst the side impact crashes, those for which a side airbag is likely to be effective and those for which it is not. Previous studies actually suggested that there is a quite large variety of side impacts, due to variety of delta-Vs, impact angles, body motions, obstacles, location of impact. Two examples from this work are given in this paper.
- Finally, in-depth accident data from France (LAB database), the United Kingdom (CCIS) and Germany (German In-Depth Accident Study, GIDAS) have been compiled to conduct the risk and effectiveness analysis. 2,035 fully documented side impact accident cases were collected from 3 institutes in the 3 countries (Laboratory of Accidentology, Biomechanics in France, Vehicle Safety Research Centre in the UK and Medical University Hannover in Germany). Out of these 2,035 cases, we retained only 435 occupants of passenger cars (front and rear). This restriction is due to the selection of relevant cases only:
- Cars built from 1998 onwards involved in an injury accident between year 1998 and year 2004 in order to compare only newer cars.
- EES[1] values between 20km/h and 50km/h as we expect absence of relevance of side airbags at low and very high speeds.
- The occupants belted or not, were sitting on the struck side, whatever the obstacle and type of accidents (intersection, loss of control, etc.).
- For multiple impact crashes, the side impact is assumed to be the more severe one.
- Just a few cases were available with head airbags or combined head and thoracic airbags, Therefore, the analysis is mainly focused on thoracic airbags and thoracic injuries.

Data from the three countries were combined into a single file for analysis. Simple descriptive statistics were not computed as the varying nature of the case selection criteria would not result in meaningful data descriptions. Risks of injury were calculated for two severity levels of thorax injury and the data were modelled using multi-variate logistic regression to control for a range of explanatory variables (velocity – impact zone – impact angle – occupant age and gender, etc.) and to estimate the odds ratios of side airbag injury reduction.

Results

Target population

National data provides the overall magnitude of side impacts. For example, in France, side impacts account for about 25% of fatalities (front and rear seats) and 18% of seriously injured casualties in passenger cars. In the UK data 41% of fatally injured occupants died in side impacts and 37% of seriously injured casulaties received their injuries in side impacts. 40% of the French fatalities (respectively 60% of those seriously injured) occur against another car, one third (respectively 30%) against a fixed obstacle and 25% (respectively 10%) against a light or heavy truck.

70% of the fatalities and 50% of the seriously injured casualties in side impacts occur on the struck side with intrusion. Consequently, in France, 17% of overall fatalities (70%*25%) and 9% of overall seriously injured casualties (50%*18%) are the target population for side airbags, which are supposed to work for occupants seated against the struck door. This calculation was not done for either Germany or the UK, but is supposed to give close estimations.

Case analysis

While statistical analysis and models can be used to derive a generalised view of accident data case by case reviews provide a complementary role. They are able to produce a fuller understanding of

[1] It must be underlined here that the availability of EES in the 3 different databases is the major reason for the small size of the sample. For more than 30% of the side crashes this value is not available. EES is actually difficult to estimate in side crashes. Moreover, in some cases, one prefers estimating the closing speed, the speed at impact or the EES value. However, as the three databases used offered more consistency and the largest number of cases for EES, we retained this parameter as a marker of violence of the impact.

the real-world event and help to define key factors for use in subsequent modelling. An overall review of cases can help to define the most valuable selection criteria for cases to be included in the model and to avoid outliers. They can also provide a qualitative view of the limits of protection with side airbags. An additional expert case review can also indicate injuries that would probably have occurred without side airbags and identify potential airbag induced injuries.

The CCIS database was searched for examples of cases of medium to high severity side impacts with low severity occupant thoracic injury, cases where side airbag deployment may have been effective for injury prevention and a higher injury outcome may have been expected. Two examples of the cases found are presented here.

Case 1

In this selected case a passenger car was struck in the side by a passenger car of similar size. The direction of force was between 3 and 4 o'clock (90 to 120 degrees) on the right side (this was a right hand drive UK car). The EES was estimated as 40 to 45km/h with an overall maximum crush of 46cm. The intrusion at the driver's position was measured as 34cm at both the base of window and pelvic levels, in the centre of the door.

Both the thoracic (seat mounted) and head curtain side airbags deployed at the driver's position. The belted 34 year old male driver sustained just slight AIS 1 injuries, a laceration to the right hand, graze to the right elbow and clear bruising to the right lateral thigh. The steering wheel airbag did not deploy.

Figure 1: Case 1 – side impact damage

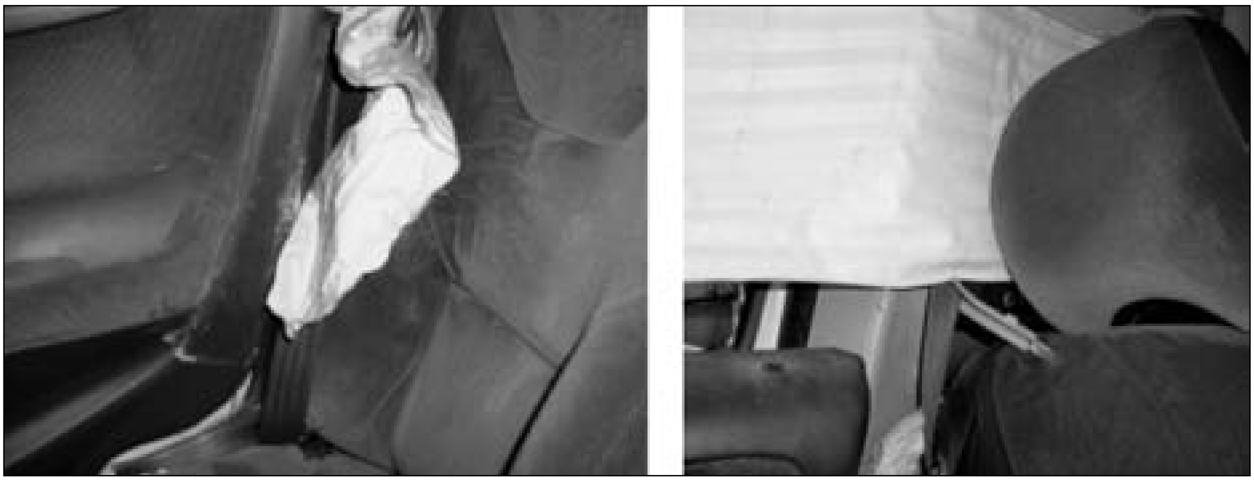


Figure 2: Case 1 – intrusion and deployed side airbags at driver's position

Case 2

A passenger car lost control in snow conditions, leaving the road and colliding with a tree. The direction of force of the impact was 4 o'clock (120 degrees) on the right side (this was a right hand drive UK car). The EES was estimated as 50km/h with an overall maximum crush of 67cm. The intrusion at the driver's position was measured as 27cm at the base of the window and 35cm at the pelvic level, in the centre of the door. It can be seen though, by comparing the intrusion patterns in cases 1 and 2, that in fact the crush profile in case 2 is more forward on the driver's position and spread over a smaller area than the car to car impact shown in case 1.

The combined thoracic and head side airbag deployed at the driver's position. The belted 32 year old female driver sustained just slight AIS 1 injuries, lacerations to the right side of the head and face, lower right leg and right hand, and contusions to the right knee, lower right leg, lower left leg, right upper arm, right posterior chest and central anterior chest. The steering wheel airbag did not deploy.

Figure 3: Case 2 – side impact damage

Risk Analysis

435 occupants of passenger cars (front and rear seats) constituted the sample. 96 passenger cars were fitted with side airbags and 339 were not. As just a few cases were available with head injuries, the analysis was focused on thoracic injuries only. The analysis consisted first of cross-tabulations comparing injury risks for different levels of EES and different types of airbags (no side airbag, thoracic only, combined thoracic and head side airbag). Table 1 shows the distribution of thoracic injuries according to EES, type of airbag and severity. Although it might be expected that the groups of deployed airbag cases might have a higher collision severity than the non-deployed Table 1 demonstrates that the group of deployed torso airbag cases sustained an almost identical collision severity distribution as the no airbag cases. The combined head and torso airbag cases tended to be involved in higher severity collisions.

Table 1 clearly shows that:

- The majority (54%) of the crashes in the sample occur at the lowest sampled level of severity (between 20km/h, the lower threshold in the selection critria, and 30km/h).
- The division of side airbags between thoracic airbags and others results in small subsamples, and even smaller subsamples when broken down by EES, which makes the comparison of injury risks broken down by airbag types difficult.
- The severity of injuries increase with EES, which comes as no surprise.

Figure 4: Case 2 – intrusion and deployed side airbags at driver's position

- The distribution of thoracic injury severity within a certain range of EES is apparently not dependent on the presence of a side airbag (regardless of the type).

	Thoracic Injuries AIS 0-1		Thoracic Injuries AIS 2+		All	
	N	%	N	%	N	%
No Side Airbag						
21-30km/h	156	81%	36	19%	192	57%
31-40km/h	65	69%	29	31%	94	28%
41-50km/h	24	45%	29	55%	53	16%
All	245	72%	94	28%	339	100%
Thoracic Side Airbag Deployed						
21-30km/h	21	81%	5	19%	26	59%
31-40km/h	9	69%	4	31%	13	30%
41-50km/h	2	40%	3	60%	5	11%
All	32	73%	12	27%	44	100%
Combined Head and Torso Airbag Deployed						
21-30km/h	13	77%	4	24%	17	33%
31-40km/h	16	67%	8	33%	24	46%
41-50km/h	5	46%	6	55%	11	21%
All	34	65%	18	35%	52	100%
All	311	72%	124	29%	435	100%

Table 1: Distribution of thoracic injuries according to EES, type of side airbag and impact severity

This first analysis was considered not sufficient because it did not provide us with a statistical multivariate estimation of the effectiveness of side airbags. This multivariate analysis is systematically required when there is a suspicion of confounders between the groups to be compared (HOSMER & LEMESHOW, 2000; PAGE, 1998). We then computed a logistic regression with injury variables (i.e. thoracic injuries AIS 2+ or AIS 3+) as the dependant variable and other variables (gender, age, airbag type and EES) as explanatory injury risk factors. Results showed a reduction in thoracic AIS 2+ and AIS 3+ injury risk in side airbag equipped vehicles in the EES 20km/h to 50km/h range, i.e. an odds ratio of 0.83 for thoracic side airbags compared to no side airbag (Table 2). However, even positive, these estimations are not statistically significant (large 95% confidence intervals).

Table 2 also shows that gender has a large but non-significant effect on injury outcome, males were 34% more likely to sustain AIS 2+ torso injuries and

Logistic Regression: Dependant Variable: Thoracic Injuries AIS 2+					Logistic Regression: Dependant Variable: Thoracic Injuries AIS 3+		
N=375 (111 AIS 2+) AIC: 411 SC: 438 -2 Log L: 397					N=375 (102 AIS 3+) AIC: 404 SC: 431 -2 Log L: 390		
	Odds ratio	Min. Limit (95%)	Max Limit (95%)		Odds ratio	Min. Limit (95%)	Max Limit (95%)
Gender Reference: Female Male	1.34	0.80	2.23	Gender Reference: Female Male	1.25	0.75	2.10
Age	1.03	1.02	1.04	Age	1.03	1.01	1.04
Type of Bag Reference: no bag				Type of Bag Reference: no bag			
Other bag deployed	0.98	0.49	1.97	Other bag deployed	0.90	0.44	185
Thoracic Bag Deployed	0.83	0.37	1.86	Thoracic Bag Deployed	0.83	0.37	1.88
EES Reference: 21-30				EES Reference: 21-30			
31-40km/h	1.91	1.09	3.33	31-40km/h	1.92	1.10	3.37
40-50km/h	5.82	3.06	11.07	40-50km/h	5.68	2.99	10.79
	Percent agreement: 74% Percent disagreement: 25.7% Percent tied: 0.4% Pairs: 29 304 Somer's D=0.48 Gamma=0.48 Tau-a=0.20 c=0.74				Percent agreement: 72.5% Percent disagreement: 27.1% Percent tied: 0.4% Pairs: 27 846 Somer's D=0.45 Gamma=0.46 Tau-a=0.18 c=0.73		

Table 2: Results of Logistic Regressions (Logit Models)

25% more likely to sustain AIS 3+ injuries compared to females. Increasing age and collision severity were also both significant factors in determining injury outcome, both being related to increasing risks of injury.

Discussion

The effectiveness of side airbags in the real-world has been studied for about 5 years. It started with case reviews and then with attempts to determine with appropriate statistical methodologies whether or not an occupant involved in a near side crash sustains injuries with a lower level of severity in a car with a side airbag than in a car without a side airbag. All studies stated the difficulty to conduct such an effectiveness analysis, mainly because:

- The complexity and the variety of real-world side crashes were considerable. The examination of cases shows that in some cases there is no influence on occupant injuries (due to crash type or low crash severity) or crash severity is too high to expect injury mitigation. Additionally in some cases there is a possible causal relationship between the injuries to the adjacent occupant and deploying side airbag.
- The low number of side airbag fitted cars involved in side crashes as this feature is rather new, even though now largely fitted cars as standard equipment. Consequently, statistical analysis often ends up with contradictory, unexpected, non explainable or non significant estimations.
- The variety of side airbags types (thoracic protection only, thoracic and head, or thoracic and head seperated) along with the difference in mounting on the door or the seat for thoracic side airbags. Consequently the injuries addressed are also varied. The statements for evaluation demand even larger samples.

Unfortunately, crash selection and the limited number of cases do not allow the estimation of effectiveness according to different types of side airbags for different crash configurations. Our result then holds only for thoracic airbags.

Case analysis

In case example 1 it is thought likely that side airbag deployment has had a positive effect on thoracic injury outcome (and in fact head injury as well). This was a substantial side impact to the driver's area and only slight, AIS 1, injuries have occurred. This paper has not systematically investigated cases without side airbag deployment so it cannot give a completely balanced view and suggests that thoracic injury would definitely have occurred without a side airbag, but this case is thought to be a good example of valuable deployment.

In case 2 it is less clear what effect side airbag deployment has had on thoracic injury outcome during individual case analysis, due to the crash configuaration and impact pattern. The impact is narrower than in case 1 whilst the area of crush is undoubtedly in the driver's area it is more concentrated on the leg rather than the torso. The driver was 160cm and 70kg which would not necessarily indicate she was sitting far forward in normal driving conditions. The impact was also more clearly from behind the driver than in case 1 (4 o'clock direction of force) so the driver would not have been moved forward into the maximum intrusion zone by the impact. Bruising on the back of the driver supports this. Due to these reasons it is likely that side airbag deployment has had less of an effect than in case 1.

The two case examples given in this paper give an illustration of how changes in crash configuration, that may not be identified in overall statistical analysis, may have an effect on the influence that the deployed side airbag has on injury outcome. Obviously it is possible to separate tree/pole impacts with those involving other vehicles in overall statistical analysis, but only if case numbers allow such a breakdown. Less likely is that the exact location of intrusion and exact direction of force can be appreciated in an overall statistical analysis for side impacts.

Statistical analysis

This paper proposed an additional evaluation of the effectiveness of side airbags in preventing thoracic injuries to passenger car occupants involved in side crashes. In-depth accident data from France, the UK and Germany have been collected and combined in a single dataset (which is rather rare and thus innovative) but the sample size remained low. Out of 2,035 side impact accident cases available in the databases, there were 435 occupants of passenger cars (built from 1998 onwards) involved in an injury accident between year 1998 and year 2004 for EES values between 20km/h and 50km/h – the conditions where side airbags were expected to show an injury reduction effect.

The logistic regression analysis, aimed at estimating the odds ratio corresponding to the deployment of a side airbag (supposedly protecting the thorax or both the thorax and the head) versus no side airbag, was not able to conclude with a statistically significant estimation of the odds ratio. However, the estimation is positive (OR=0.83 for the reduction of AIS 2+ and AIS 3+ thoracic injuries). Furthermore, case reviews in the literature suggest that side airbags should have an overall benefit for head and thorax protection.

The absence of statistical significance is assumed to be due to lack of statistical power due to a low number of cases. A significant odds ratio of 0.83 would have needed a sample size of 8,400 accident cases for 1-=95% and a statistical power of 80%.

Another possibility lies in the combination of the 3 accident databases that were used: LAB (France), CCIS (UK) and GIDAS (Germany). It is possible that the estimation of violence of impact, i.e. EES, has not been carried out the same way by different experts. Some data were also missing. On the other hand, we were not able to add more variables in the regression analysis or in the selection criteria. Impact angles, hit obstacle, CDC deformation, location of impact were not used, because they were not systematically available in the databases. Their availability would have permitted a larger sample and the consideration of additional confounders.

Unfortunately, statistical analysis for head injuries was not possible due to the low number of accident cases with passenger cars fitted with head side airbags in the databases.

The results are nevertheless encouraging and suggest that a larger sample size should be available soon, either by combining more European databases or by waiting for the databases used here to get additional side impact cases.

This paper uses accident data from the United Kingdom Co-operative Crash Injury Study. CCIS is managed by TRL Ltd on behalf of the Department for Transport (Transport Technology and Standards Division) which fund the project with Autoliv, Ford Motor Company, Nissan Motor Europe and Toyota Motor Europe. The data were collected by teams from the Birmingham Automotive Safety Centre of the University of Birmingham, the Vehicle Safety Research Centre at Loughborough University, and the Vehicle and Operator Services Agency of the Department for Transport. Further information on CCIS can be found at http://www.ukccis.org.

References

P. BAUER, W. LANGE: Comparison of real-world side impact/rollover collisions with and without thorax bags – First field experience study, 44th AAAM Conference, Chicago, 2000

J. BOUYER, D. HÉMON, S. CORDIER, .F DERRIENNIC, I. STÜCKER, B. STENGEL, J. CLAVEL: Epidémiologie, principes et méthodes quantitatives. Paris, France: Les éditions INSERM, 1995

E.R. BRAVER, S.Y. KYRYCHENKO (2004): Efficacy of side air bags in reducing driver deaths in driver-side collisions. American Journal of Epidemiology 159:556-64

D. DALMOTAS, A. GERMAN, S. TYLKO: The crash and field performance of side-mounted airbag systems, 18th ESV Conference, paper n° 442, Amsterdam, May 2001

D. HOSMER, S. LEMESHOW: Applied Logistic Regression (Second Edition). New York, NK, USA: John Wiley & Sons, 2000

A. KIRK, A. MORRIS: Side airbag deployments in the UK, initial case reviews, 18th ESV, Paper n° 100, Nagoya, Japan, June 2003

G. McGWIN, J. METZGER: Association between side airbags and risk of injury in motor vehicle collisions with near-side impact. Journal of Trauma 55-3, p. 430-436, 2003

A. MORRIS, R. WELSH, P. THOMAS, A. KIRK: Head and chest injury outcomes in struck side crashes, IRCOBI Conference, Prague, CZ, September 2005

D. OTTE, M. RICHTER: Influences on the injury situation of side airbags for belted struck-side front car occupants in lateral impact conditions, an in-depth analysis by GIDAS, 6th Bag and Belt Conference, Cologne, May 2006

Y. PAGE (1998): Un exemple d'application de la régression logistique à l'évaluation d'une mesure de sécurité routière. Observatoire National Interministériel de Sécurité Routière

Y. PAGE (1998): Utilisation de l'odds ratio comme mesure du risque relatif. Application à l'estimation du sur-risque des véhicules neufs versus les véhicules anciens. Note interne. Centre Européen d'Etudes et de Sécurité et d'Analyse des Risques. Nanterre

A.K. PRASAD, R. RSAMAHA, A.E. LOUDEN: Evaluation of injury risk from side impact airbags, 18th ESV Conference, paper n° 331, Amsterdam, May 2001

S. SCHNEIDER, M. NIWA, T. KOTAMA, T. TANASE, Y. SATO, M. SAKAMAOTO, M. ASAOKA: Effectiveness of thorax and pelvis side airbag for improved side impact protection, 19th ESV Conference, paper 05-0273, Washington, June 2005

S. TYLKO, D. DALMOTAS: Side airbags: evaluating the benefits and risks for restrained children, 18th ESV Conference, paper n° 420, Amsterdam, May 2001

N. YOGANANDAN, F.A. PINTAR, T.A. GENNARELLI: Evaluation of side impact injuries in vehicle equipped with side airbags, IRCOBI Conference, Prague, CZ, September 2005

N. YOGANANDAN, F.A. PINTAR, T.A. GENNARELLI: Field data on head injuries in side airbag vehicles in lateral impact, 49th AAAM Conference, September 12-14, 2005

P. Thomas
Vehicle Safety Research Centre, Loughborough University, UK

Comparative Accident Rates of Vehicles Equipped with Stability Control – Field Experience

Abstract

This paper uses the national accident statistics of Great Britain to evaluate the effectiveness of Electronic Stability Control Systems (ESC) to reduce crash involvement rates. The crash experience of 8,951 cars is analysed and compared to a closely matching set of non-ESC cars using case-control methods. This is one of the largest ESC samples analysed to date. Overall the cars with ESC are involved in 3% fewer crashes although the effectiveness is substantially higher under conditions of adverse road friction. ESC equipped cars are involved in 15% fewer fatal crashes although this reduction represents the combined effect of ESC and passive safety improvements.

Introduction

The introduction of new active safety technologies promises substantial future reductions in vehicle collisions, by reducing overall crash numbers fatalities, injured road users and property damage can potentially be reduced. Some systems may merely aid the driving task increasing driver comfort levels and enhancing the driving experience. Other systems can have an advisory function and feed information to the driver on road conditions and route directions for example. Additionally they may take control over aspects of the operation of the car modifying the dynamic performance in response to road conditions. When introducing a new system that has the intention of improving safety it is important that these systems are targeted to achieve high levels of casualty reduction to ensure that consumer expectations are fulfilled and confidence is maintained. Analysis of high frequency and high risk crash conditions can give clear prioritisation of the functionality of new technologies before they enter the car fleet on the road. Once on the road in sufficient numbers it is important to measure the true casualty reduction effectiveness in order to confirm the value of the technology and to avoid high profile technologies with little real-world value.

New technology systems are normally designed to operate under a range of driving conditions and this can determine the evaluation method. While it can be gratifying to have high effectiveness values in certain conditions, if these conditions are relatively rare there may be little overall effect. For that reason it is necessary to evaluate the overall effectiveness, the effectiveness under specified conditions and the exposure to those conditions as part of the same evaluation. In the absence of suitable multi-centre studies evaluation has to take place when the numbers of equipped vehicles are large in a particular country or study area. The more effective the system the more difficult it is to evaluate.

Electronic stability control (ESC) is a system that modifies the vehicle dynamics to reduce the incidence of over-steer and under-steer and hence reduce loss of control crashes. There have been evaluations of the system effectiveness but mostly these address the design conditions excluding the overall effect (BECKER [1],AGA and OKADA [2],FARMER [3], and DANG [4]). This analysis uses the UK National Accident Database STATS 19 to evaluate the overall casualty reduction effectiveness of ESC together with the exposure to a variety of real-world conditions.

Crash Data

Crashes occurring in Great Britain, resulting in injury and reported to the police are entered onto the national register called STATS 19 [5]. The data for 2002–2004 has been combined electronically with vehicle licensing information so that the make, model, variant and manufacture year is known. The data were further enhanced with details extracted from standard car data texts [6] and the final dataset comprised 890,648 cars of which 8,685 were equipped with ESC. This represents one of the largest datasets available for this type of analysis.

The analysis utilises a case-control approach based on methods of induced exposure [7]. A set of case vehicles was defined so that each car was known to have been equipped with ESC. Models where the equipment was optional were excluded from the case vehicle group. A comparable group of control car models was defined and in general the previous version of a case vehicle not equipped with ESC was selected. There were 41,318 control cars in the dataset. In some cases ESC was first introduced to relatively high performance variants of a model so the control vehicles were themselves the previous unequipped high performance variants. It should be noted that the case-control method compares the two groups of vehicles in total and thus any differences in crash risk reflect all of the differences between the case and control cars. Cars equipped with ESC will also have anti-lock braking systems (ABS) and probably traction control as these functions can be achieved by the same software and hardware, also a more recent model may have other improvements to the suspension and handling performance that are not identified and the case control method is not able to separate out these effects. Previous examinations on the effectiveness of ABS have shown the effects to be small e.g. EVANS [8] and this analysis makes the assumption that differences in crash involvement between case and control cars are predominantly due to the presence of ESC.

The case control approach also requires a set of crash types where there is an expectation that ESC will have no effect to be used as a control group. If the control crashes are sensitive to the presence of ESC then its effectiveness may be under- or over-estimated. The GB STATS 19 data includes several categories of vehicle manoeuvres where one car was essentially stationary before the crash and these were selected to be the control group of manoeuvres. These are listed in Table 1 together with the other collision types in the case group where ESC is not assumed to have no effect.

Using the case-control methodology the cars in the sample are distributed between the four case-control categories as shown in Table 2.

It should be noted the case-control method does not assume that vehicles are in the same collision. The case control method calculates the odds of a case car being involved in the two crash types (Eq. 1) and the odds ratio is used to compare the two groups of cars (Eq. 2). The effectiveness of ESC is defined in (Eq. 3) and the standard deviations are given in (Eq. 4).

$$Odds_{ESC}\left(\frac{Control}{Case}\right)=\frac{N_{00}}{N_{01}} \quad [1]$$

Control Manoeuvre types (assumed no ESC effect)	Other Manœuvres (ESC effect possible)
Reversing	U turn
Parked	Turning left
Waiting to go ahead but held up	Turning right
Stopping	Changing lane to left
Starting	Changing lane to right
Waiting to turn left	Overtaking moving vehicle on its offside
Waiting to turn right	Overtaking stationary vehicle on it's offside
	Overtaking on nearside
	Going ahead left hand bend
	Going ahead right hand bend
	Going ahead other

Table 1: Case and control collision types

	Control manoeuvre types	Other manoeuvre types
Case vehicle (ESC)	N_{00}	N_{01}
Control vehicle (no ESC)	N_{10}	N_{11}

Table 2: Case and control contingency table

$$\text{Odds ratio}=\left(\frac{Odds_{ESC}}{Odds_{noESC}}\right)=\frac{N_{00}}{N_{01}}\bullet\frac{N_{11}}{N_{10}} \quad [2]$$

$$\text{Effectiveness}_{ESC}=(1\text{-Odds ratio})\bullet 100\% \quad [3]$$

$$SD=\text{Odds ratio}\bullet\exp\left(\sqrt{\frac{1}{N_{00}}+\frac{1}{N_{10}}+\frac{1}{N_{01}}+\frac{1}{N_{11}}}\right) \quad [4]$$

These methods were used to evaluate the effectiveness of ESC in reducing crashes under a range of collision circumstances and for a range of injury severity outcomes.

Results

The UK accident data record the severity of the injuries sustained in the crash. Fatal crashes include at least one casualty that has died within 30 days of the crash, seriously injured casualties have sustained at least a fracture or have been detained in hospital at least overnight while slightly injured casualties have sustained lower severity injuries, normally lacerations and contusions. The distribution of accident severity in the data is shown in Figure 1.

Figure 1 shows that 88% of all crashes involved casualties which sustained only slight injuries while casualties were killed in only 1%. The reductions of these casualties in vehicles equipped with ESC are shown in Figure 2 for all crashes, crashes where a car occupant was either killed or seriously injured (KSI) and fatal crashes. Overall ESC equipped cars were involved in 3% fewer crashes than non-equipped vehicles but KSI crashes were 19% lower and fatal crashes were 15% lower, although this result was not statistically significant.

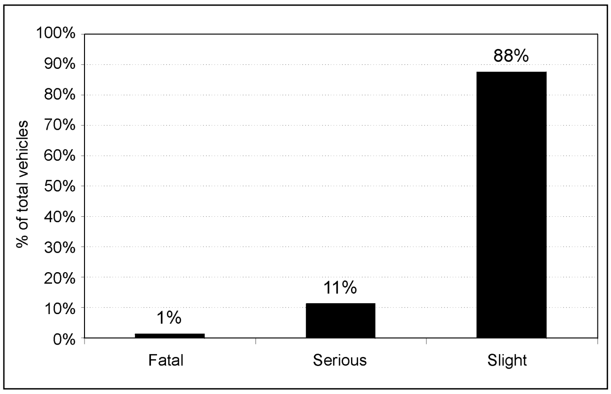


Figure 1: Accident severity

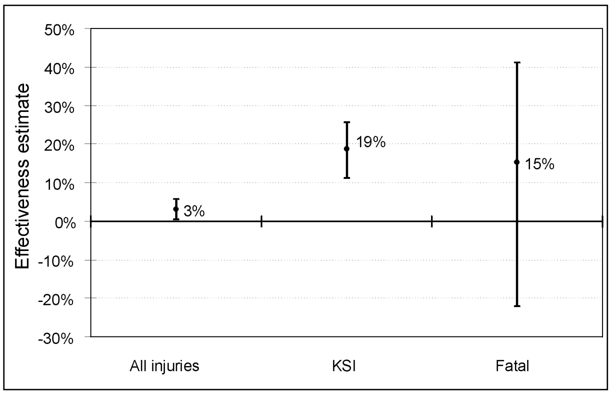


Figure 2: Reduction in crash rates for ESC equipped cars

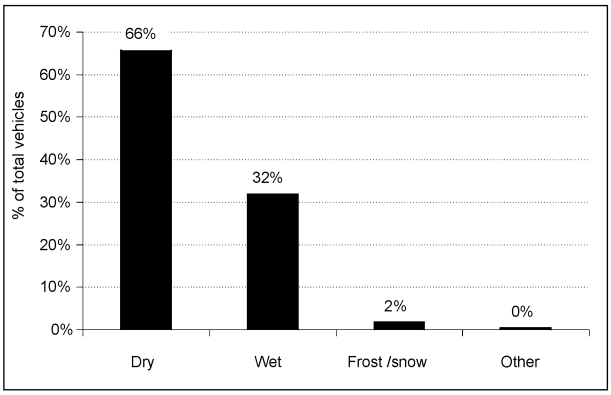


Figure 3: GB crashes and road surface conditions

Road surface conditions

ESC systems are intended to give benefit under poorer road surface conditions where friction is reduced such as wet or icy. The frequency these conditions occur under normal driving depends on the prevailing climate and local conditions. Figure 3 shows the proportion of accident occurring in the GB on dry, wet and snow/icy road surfaces. The majority, 66%, of crashes took place on dry roads while ice and snow was a factor in only 2%.

Figures 4 to 6 show the effectiveness of ESC for each accident severity level on each condition of road surface.

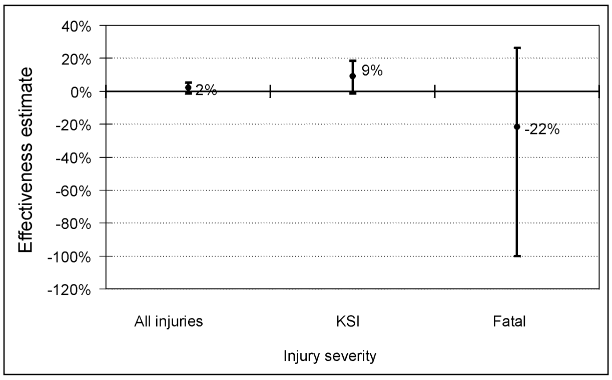


Figure 4: ESC effectiveness on dry roads

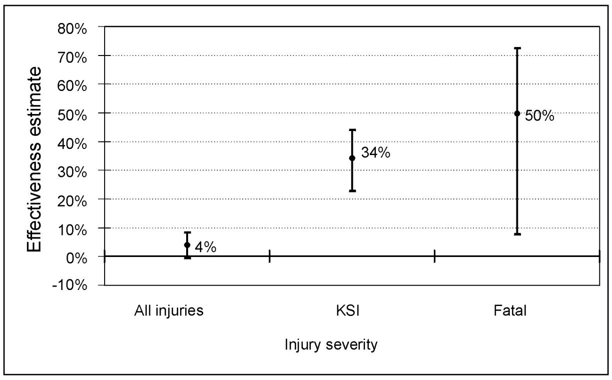


Figure 5: ESC effectiveness on wet roads

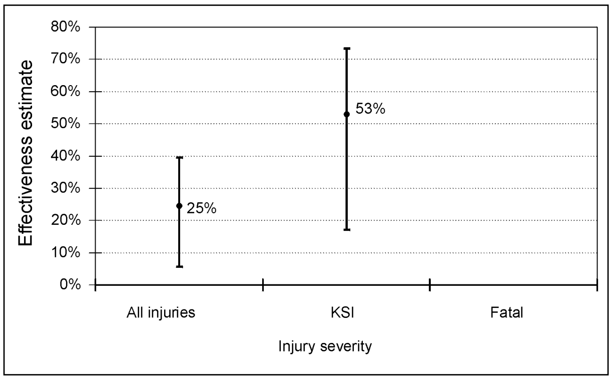


Figure 6: ESC effectiveness on snow or icy roads

On dry road conditions ESC equipped cars were involved in 2% fewer crashes overall and 9% fewer KSI crashes. Fatal crashes were 22% more common although none of these changes was statistically significant.

On wet roads ESC systems showed lower involvement rates for crashes of all severities. Fatal crashes showed a 50% reduction while KSI crashes were 34% fewer.

On snow or icy road conditions ESC equipped cars had substantially fewer crashes. Overall there were 25% fewer crashes while KSI crashes were reduced by 53%. There were insufficient cases to evaluate fatal crash reductions of ESC fitted vehicles.

Impact direction

By limiting understeer and oversteer ESC is intended to reduce loss of control collisions and it has been hypothesised that side impacts will be preferentially reduced compared to frontal collisions (REIGER et al. [9]). The GB accident data include an assessment of the first point of impact to the vehicle conducted by the police officer dealing with the crash. This assessment is not as precise as one done by trained crash investigators but it does provide an indication of the impact direction. The frequency of each point of impact is shown in Figure 7 and the reductions in crashes in front and side crashes in Figures 8 and 9.

The car front was the first point of impact of 48% of the cars in the GB accident data while 24% of impacts were to the side of the car.

Frontal collisions of all severity levels were 10% lower in ESC equipped cars while side impacts reduced by 7%. KSI crashes were 18% lower in collisions to the front of the car and 28% lower in side crashes. Fatal crashes were 38% higher in ESC equipped cars in side impacts although there were insufficient cars to evaluate changes in frontal fatalities. None of these differences between front and side impact was statistically significant as was the apparent increase in fatalities.

Car size class

Generally the first installations of ESC equipped cars tended to be those with higher specifications. More recently the systems have been installed onto less well equipped including family cars. Each of these types of car will attract a different population of drivers and there may be differences in the effectiveness of ESC under these conditions. The size of the car was grouped according to the system used within the EuroNCAP programme and the frequency of these categories is shown in Figure 10 which also shows the total number of different models of car in each group.

It should be noted that only four different models of Superminis were equipped with ESC and all of these were high-performance versions. Therefore effectiveness results of this car size may not be

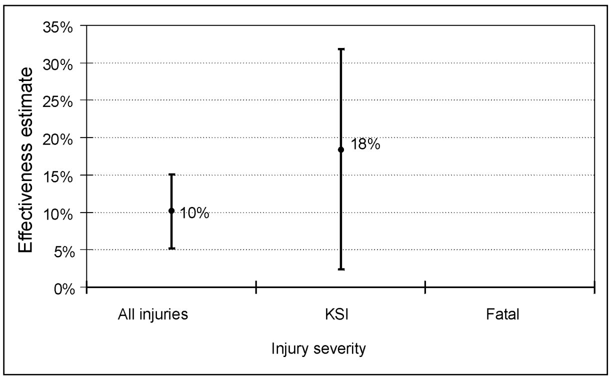


Figure 8: ESC effectiveness in impacts to the car front

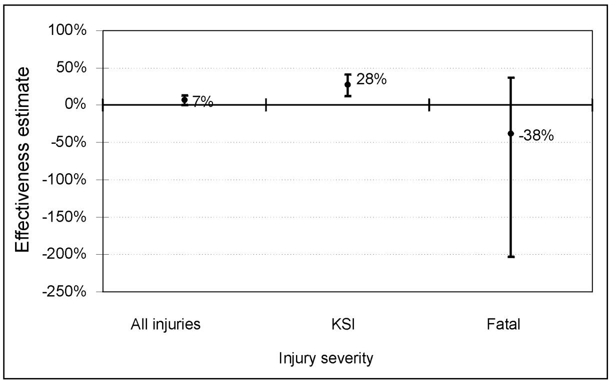


Figure 9: ESC effectiveness in impacts to the car side

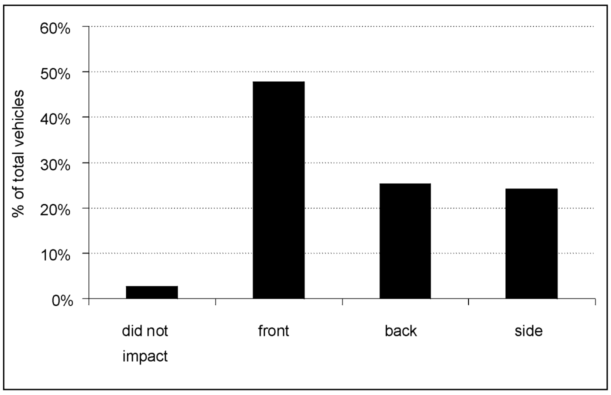


Figure 7: Frequency of impacts to car surfaces

typical of other cars in this category. The most common categories in the GB accident data were small and large family cars together representing 78% of the car fleet.

The effectiveness of ESC in reducing crashes of all injury severities in each of these car size categories is shown in Figure 11. Figure 12 shows the equivalent results for crashes involving fatal or serious injury.

Small family cars showed a non-significant increase in crash rates of 2% for the ESC equipped cars while large family cars had a 13% lower crash rate. Large off-roaders showed a 24% increase in crash rates. Small MPVs, with just one model of car, showed a 74% lower crash rate while large MPVs with 2 models showed a 29% increase.

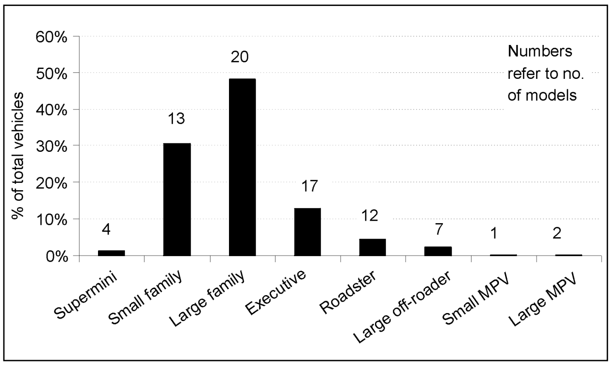


Figure 10: Car size category and number of models

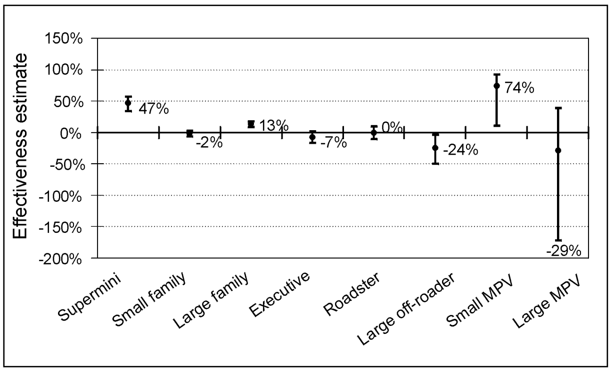


Figure 11: ESC effectiveness in crashes of all injury severities

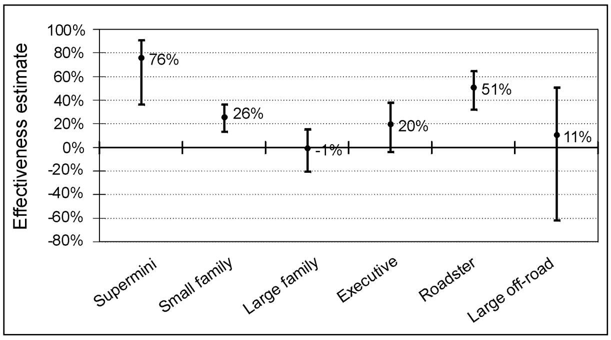


Figure 12: ESC effectiveness in KSI crashes

In crashes involving fatal or serious injury small family cars had a 26% lower accident rate while large family cars showed a 1% increase. Executive cars had a 20% lower crash rate and roadsters had a 51% lower rate.

Discussion

This analysis of GB national accident data has indicated that cars equipped with ESC are involved in 3% fewer crashes overall compared to unequipped cars. This compares to 22% effectiveness in Sweden and 45% in Germany using similar methods. The analysis has shown that ESC is most effective under poor road surface conditions such as rain, snow and ice where the effectiveness increases to 25%. The data also indicates that these conditions are relatively rare in Great Britain with only 2% of crashes taking place on snow or icy roads.

Although the benefit to Great Britain from ESC does not appear to be as large as in other countries with more frequent adverse road surface conditions it is nevertheless still significant in financial terms. In 2004 there were 292,000 cars involved in crashes in GB, most of which were not equipped with ESC, these results indicate that if they had been there would have been nearly 9,000 fewer crashes. The UK Department for Transport has estimated the average cost of a crash to be £62,197 in 2004 values [10] so the total saving resulting from uniform fitting of ESC to cars is £544,845,720 (€730,093,265).

Limitations

The methodology used for this analysis, while powerful, does have a number of limitations. Most importantly, it assumes that ESC equipped cars and the control models differ only by the presence of ESC. However when a model of car is replaced by an new version a manufacturer will normally make a collection of changes. There may be other changes to the vehicle dynamics system that also reduce crash involvements – this analysis assumes this factor is negligible. If there are significant effects these will be included in the estimates of crash involvement of the group of all injury severities. In particular a manufacturer may also make improvements to the passive safety performance of the car by modifying the structure or restraint systems. These improvements will reduce the risk of serious or fatal injury and hence the changes in the rates of these crashes in the analysis will reflect the combination of ESC and passive safety changes. Given the rapid and large improvements to passive safety the magnitude of these effects may not be negligible.

Conclusions

This analysis of the GB national accident data has shown that cars equipped with electronic stability control systems have a lower crash involvement rate than non-equipped cars. The overall reduction for crashes of all injury severity is 3% but on icy roads or snow this rises to 25% but the accident data show that only 2% of crashes occur under these conditions.

Acknowledgements

The author would like to thank the DfT for the use of the STATS 19 data which provide a very valuable resource to examine the effectiveness of active safety systems. Marianne PAGE and Lucy RACKLIFF at the VSRC prepared the background literature for this work.

References

[1] H. BECKER, et al.: Großzahlenmaterial, “In-Depth”-Erhebungen und Einzelfallanalyse, Werkzeuge zur Verbesserung der Fahrzeugsicherheit im Volkswagenkonzern (Large number material, in-depth studies and single case analysis – tools for improvement of vehicle safety at Volkswagen Group). 1. Dresdner Tagung, “Verkehrssicherheit inter-disziplinär”, 27.-28. June 2003 (in German)

[2] AGA and OKADA (2003): Analysis of vehicle stability control (VSC)s effectiveness from accident data. Paper no 541, Proceedings of the 18th International technical Conference on the Enhanced Safety of Vehicles. NHTSA, Washington DC

[3] C.M. FARMER (2004): Effect of electronic stability control on automobile crash risk, Traffic Injury and Prevention 5: 317 – 325, 2004

[4] J.N. DANG (2004): Preliminary results analyzing the effectiveness of electronic stability control (ESC) systems, National Highway Traffic Safety Administration, US Department of Transport, September 2004. Report number DOT-HD-809-790

[5] Road Casualties Great Britain 2004: The Stationery Office, September 2005

[6] Glass’s Guide Car Checkbook 2005

[7] L. EVANS: Double paired comparison – a new method to determine how occupant characteristics affect fatality risk in traffic crashes. Crash Analysis and Prevention, Vol. 18, no. 3, pp. 217-227, 1986

[8] L. EVANS: Antilock brake systems and risk of different types of crashes in traffic. ESV Conf paper no. 98-S2-O-12. Windsor 1998

[9] L. RIEGER, J. SCHEEF, H. BECKER, M. STANZEL, R. ZOBEL: Active safety systems change accident environment of vehicles significantly – a challenge for vehicle design

[10] Department of Transport: UK Highways economic note No.1: 2004. London 2004

M. Hoppe, M. Junge, M. Jungmichel, K. Seifert
Volkswagen AG, K-GEFFB/S Unfallforschung,
Wolfsburg, Germany

Ideas and Expectations of Intersection Assistance

Abstract

The objective of this study was to identify aspects of the individual experience and behaviour of drivers in intersection accidents. A total of 40 accident drivers sketched their ideas and expectations relating to intersection assistance using the method of Structure Formation Technique. Using this method prepared content cards and relation cards for a subject matter are formed together in a structure through the application of an explicit set of rules. The structures generated in this process were compared with the structures of 20 control persons who have not recently experienced an accident at intersections. The basis for this comparison was a case-control design with matched samples regarding the variables age, sex, education, occupation, driving experience and annual mileage.

The results of the accident reports indicate that additional assistance is instrumental in the perception of other road users. Generally the interviewed drivers were open-minded towards the use of intersection assistance systems. Drivers who have recently experienced an accident at intersections significantly more often approved of warning assistance in their vehicle than drivers who have not recently experienced an accident. Further accident experienced drivers favoured warning and information via audio warning more frequently. The ideas of the drivers were strongly shaped by the experiences with already available advanced driver assistance systems. Hence acoustic and visual warnings were generally preferred to tactile warnings. The findings also indicate a relationship between the variable age and the acceptance of automatic vehicle intervention, and the suggestion of a head up display as a configuration of a visual warning system.

Introduction

It is the ambition of accident research in vehicle industry to investigate accident events as a whole. For that purpose engineers, physician and psychologists work together interdisciplinarily.

Using the data concerning the vehicle, the injuries of the car occupants, the environmental conditions and the resulting reconstruction of the accident events, it is the objective of accident research to generate information for the technical development of vehicles. Therefore the main focus has traditionally been the development of systems for passive safety. However, in recent years the focus has shifted to concerns of active safety and hence the collection of psychological data relating to the pre-crash phase has become essential. Psychological accident data particularly refer to perception, cognitive procedures, attention as well as risk taking, motives and social interaction of the road users (SCHLAG, 1999). It is of importance to gain expertise about how people experience accidents and how they behave in particular critical situations. Furthermore it is of specific interest which driving tasks demand need for assistance. In order to answer this question it is essential to ask drivers for needs, expectations and ideas concerning advanced driver assistance systems.

In the past decades it was usual in product development that evaluation studies were only applied after products had been introduced onto the market. Such procedures hold the risk of inappropriate developments (HEMMERLING, 1998, SACHSE & HACKER, 1995). Applied in the vehicle industry, inadequate designs of advanced driver assistance systems (ADAS) might lead to so called negative behaviour adaptation (WELLER & SCHLAG, 2004). Hence in the mid-eighties there was a short-term rise in rear end crashes after the introduction of the anti-lock braking system in Germany (REICHLE, 1989). A possible explanation for this phenomenon is a misunderstanding of the drivers of the new system as a brake enhancing system.

It is an underlying assumption that individuals have representations in their mind about why things or systems are existing, how they are operating, what they are doing and what they look like (ROUSE and MORRIS, 1986). Those representations are called mental models. They depend on the experience, goals and tasks of the users of systems as well as the design of the system and the communication of the system function. Mental models are kept in mind by the users of systems as long as they are plausible (KLUWE, 1992; SEEL, 1991; DUTKE, 1994). In conclusion it is important to involve future system users in the process of product development, especially in designing the human-machine interface, so that negative behavioural adaptations in consequence of inadequate mental models can be avoided (HEMMERLING, 1998).

For this study an intersection assistance system was chosen, in order to show the benefit of interviewing potential system users, because such a system has not been introduced onto the market yet. Besides that, accidents at intersections have a high prevalence (about one third of the accidents in Germany in 2004 happened at intersections) and therefore cause high economic costs. Furthermore, especially elderly drivers have a higher incidence at complex intersections and junctions (ENGELN & SCHLAG, in press), and since the number of elderly drivers is expected to rise in near future, it is important to research intersection assistance systems.

The following questions are to be answered in the course of this paper: What can be learned from reports about accidents at intersections? Is there a general need for intersection assistance? In which situations and on which level do drivers wish for an intersection assistance system? How should an intersection assistance system be designed to effectively assist the driver of a vehicle? Which factors are influencing the ideas and expectations on intersection assistance?

Method

Participants

The sample consisted of 40 drivers who experienced an accident at an intersection in the period from January 2004 to June 2005. 20 of those accidents were investigated by the accident research team of Volkswagen in the region of Wolfsburg and Braunschweig. This part of the sample was compared with a control group of 20 drivers who had not experienced an accident at intersections in recent years. The other 20 accidents were investigated by the accident research team of the Technical University Dresden in and around Dresden. The aim of study this second sample was to confirm the statements deduced in the first part of the research program.

The participation in this study was voluntary and honoured with a small gift at the end of the session.

Apparatus

In order to explore the ideas and expectations of intersection assistance the 40 accident drivers were questioned about their individual accident experience with the help of a structured interview manual. The objective of the interview was to explore details concerning the course of the accident, particularly the moment of perceiving the accident opponent and the consequently following reactions. Also of importance were environmental circumstances. Finally the accident drivers were asked about their opinions towards the avoidability of the accident, in order to find out about the individual view of the mistakes of the driver himself and the mistakes of their opponents, and beyond that, possibly existing mental models of the functionality of advanced driver assistance systems.

The drivers who had not experienced an accident at an intersection were asked about their experiences with accidents in general.

The method chosen to explore the mental models of the participants is called Structure Formation Technique. Under this label different strategies are summarised which support their users in producing structures that illustrate causal and explaining relations between terms of variable contents through the application of an explicit set of rules (SCHEELE & GROEBEN, 1988; BONATO, 1990; FELDMANN, 1979). In the current case the participants of the study were given a set of 46 prepared cards with terms describing and explaining intersection assistance concerning design, functionality and usage settings. They were instructed to take a look at the cards and sort out the terms which they thought of as relevant for their idea of intersection assistance. Additionally they were asked to combine the relevant terms with relation cards containing 5 different possibilities of relations: an arrow to describe chronological and spatial linkages, an equal sign which represents definitions, a card “or” used to indicate relating terms that exclude each other, a card “precondition” to characterize conditional relations and a card with two lines symbolizing hierarchical relationships between the terms. The structures were analyzed through counting frequencies of the used terms and accordingly categories were formulated.

The acquisition of demographic variables was accomplished using a questionnaire answered by the participants at the end of the exploration. The following variables were collected: age, sex, education, occupation, driving experience in years and annual mileage.

Procedure

The exploration was accomplished at the participants' home, at their work or at another neutral place. After an interview in order to examine the participants' accident experiences, they were given a pack of conceptual cards to look through and sort out and a set of relation cards. The instructor explained the procedure of the structure putting technique by means of the example of a washing machine and guided the participants through the exploration using questions based on the model of ROUSE and MORRIS (1986, see above) concerning the goals, the looks, the functioning and relevant settings of the intersection assistance system. In addition to the given content cards, the participants had the possibility of generating their own cards based on a dialog with the instructor. For the warning strategies they were required to generate their own cards. After the structure was formed, the instructor repeated the ideas in their own words and asked for complementary ideas. There was also time for discussing different aspects of the participant's structures. At the end of the exploration the participants' were asked questions about demographic variables. The whole dialog was recorded with a tape recorder in order to facilitate the analysis of the data. The exploration lasted about 60 to 90 minutes dependent on the interaction styles and the quantity of ideas of the participants.

In order to analyze the data, different strategies were used. Firstly the 20 participants that were involved in accidents investigated in the region Wolfsburg and Braunschweig were compared to the 20 participants without intersection accident experience at intersection in years following a case-control design. A precondition for realizing this design was to match the participants of these two groups concerning the variables age, sex, education, occupation, driving experience and annual mileage. The resulting pairs were analyzed using statistical methods for matched samples such as a binomial test for alternative variable characteristics. Significant results of those analyses are reported respectively. In a second step the accident samples investigated in Wolfsburg/ Braunschweig and Dresden were compared using methods for independent data. The two parts of the accident sample differed rarely concerning reviewed variables. Therefore in the following the reported results concern both parts of the sample.

Results

Structure analysis

In Figure 1 an example of a structure is shown (shortened). The participant who had formed this structure suggested a combination of information and automatic vehicle intervention in case of dangers through other road users. Therefore it is a precondition that other road users and possible dangers can be perceived with the help of sensory systems. An automatic vehicle intervention should be able to apply deceleration and emergency braking depending on the severity of the situation. The participant did not approve of automatic vehicle acceleration. Furthermore he proposed additional information about the automatic intervention of the vehicle either through a visual output like a head up display or through an acoustic output. The main goal of intersection assistance should be the avoidance of accidents. The process of structure forming was accompanied by a dialog between the participant and the instructor.

What can be learned from reports about accidents at intersections?

Drivers with accident experience at intersections either did not see their opponents at all or only just before the crash. Only 2 out of 40 drivers had seen their opponent before they crashed. Both had expected their opponent to stop because he had to wait at the intersection. These findings imply difficulties for the accident drivers concerning information admission. Having been asked about their reactions before the crash, 26 out of the 40 accident drivers answered that they had not been able to react anymore, 12 people were trying to brake. Five drivers tried to steer away from the other vehicle and one driver chose to accelerate. The success of the reaction manoeuvers can only be evaluated using the technical reconstruction data since most of the interviewees could not consciously observe the success of their reaction. Another noticeable finding is that most of the accident drivers describe how they could only react in one way and that it was impossible for them to think about two compensation strategies, for

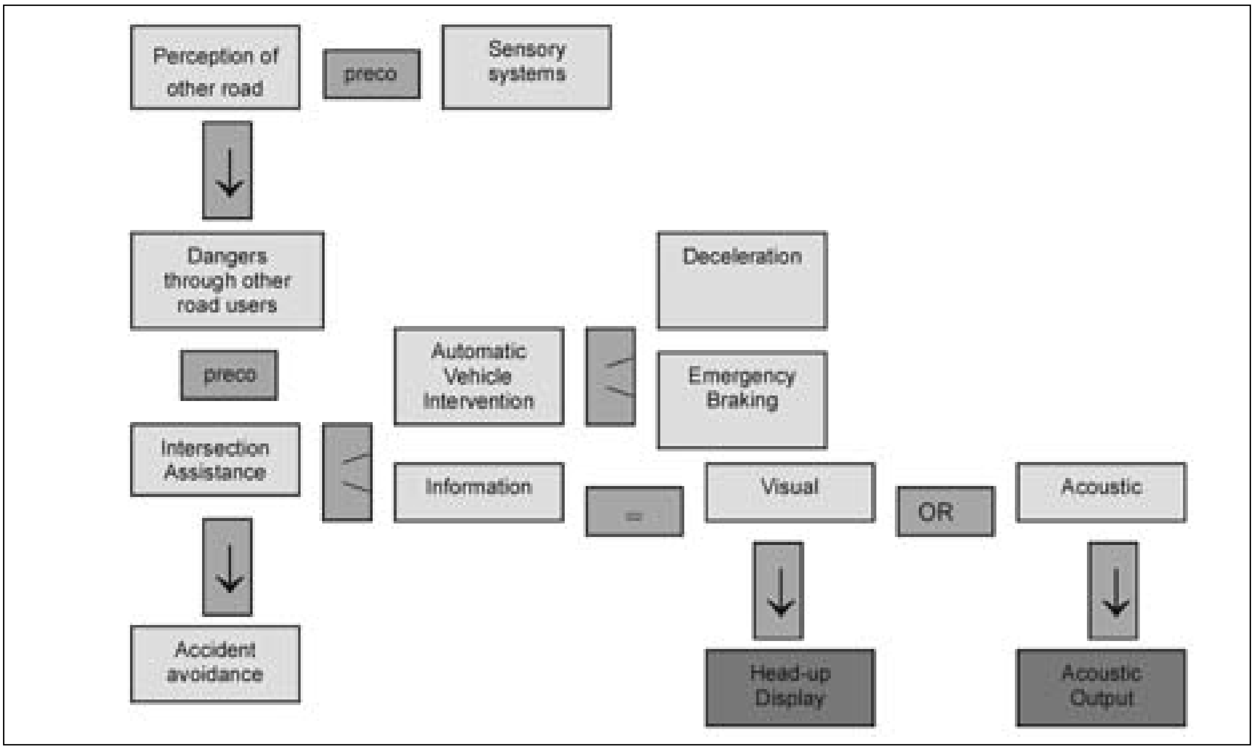


Figure 1: Example of a formed structure

example braking and drawing aside, at the same, very short, time.

Asked about the sight conditions, 12 participants reported obstructions through other vehicles, 6 could not see their opponents because of plants and trees and 4 felt impaired through sun glare. One driver described sight restraints through his own c-pillar.

Table 1 shows frequencies of drivers mentioning strategies of crash avoidance. The findings are shown separately for drivers who caused the accident (24) and for drivers who were involved in the accident (16) according to the accident record of the police. Multiple answers were possible.

One half of the accident originators reported mistakes related to deficiencies providing attention when turning at or crossing the intersections, while three quarters of the accident involved drivers did not see own possibilities of avoiding the accident. Another 12.5% of the originators and 6.25% of the accident involved drivers saw both opponents of capable avoiding the accident. The view of accidents as unavoidable naturalistic events is reflected in the opinions of 25% of the originators and 18.75% of the accident involved drivers. 21% of the accident originators and 31.25% of the accident involved drivers reported that

Avoidance	Originator		Involved Driver	
Only through actions of the opponent	6	25%	12	75%
Through more attention of oneself	12	50%	1	6.25%
Through more attention of both opponents	3	12,5%	1	6.25%
Through advanced assistance systems	1	4,2%	0	0%
Not possible: wrong time, wrong place	6	25%	3	18.75%
Through changes in environment or rules	5	21%	5	31.25%

Table 1: Frequencies of content card usage concerning strategies of crash avoidance

environmental circumstances or inadequate ruling were causal for the accident event. They suggested, for instance, establishing roundabouts. Only one interviewee suggested an advanced driver assistance system could have helped avoiding his accident. This suggestion concerned a “right of way”-display in the vehicle.

Is there a general approval of intersection assistance?

Generally the drivers who participated in the exploration were open-minded towards the use of systems assisting the drivers in turning at and crossing intersections. Only two out of 40 accident experienced drivers disliked an additional assistance system for intersections. Among the 20 interviewed drivers without accident experience at intersections 3 disliked the idea of an additional assistance system.

In which situations and on which level do drivers wish for an intersection assistance system?

Having been asked about dangerous situations at intersections and approval of assistance all 38 accident-experienced participants of the study who supported the idea of an additional intersection assistance system (95%) were of the opinion that it is reasonable to assist the drivers at intersections in perceiving other road users. Moreover, 37.5% of the accident experienced drivers approved of assistance in detecting road signs and 27.5% accident experienced drivers suggested assistance in recognizing red traffic lights. Multiple answers were possible. It was noticeable that the accident drivers were generally influenced by their own accidents. The drivers who had not experienced an accident at intersections in recent years rated the detection of road signs as relatively more important. 80% of the comments accounted for situations of perceiving other road users, 45% of the comments were related to the detection of road signs and 20% of the comments concerned the recognition of red traffic lights. These results are shown in Table 2. In brackets there are shown the results for the part of the accident sample from Wolfsburg/Braunschweig which were compared to the results of the control group following a matched samples design. There could not be found any significant differences.

The discussion about the levels of assistance revealed a wide spread acceptance of warnings in the vehicle among accident experienced drivers: 85% approved of warnings as an adequate assistance strategy compared to 70% of the drivers without accident experience. This difference was significant (p=0.0315). Information systems were not rated as effective in intersection settings. Only about one third of the accident experienced drivers (30%) as well as the drivers without accident experience favoured information strategies. Surprisingly over one half of the accident experienced drivers (60%) and 65% of the drivers without accident experience suggested automatic intervention of the vehicle especially in emergency situations. Often the participants approved of more than one level of assistance thus suggesting sequential assistance strategies.

	Intersection accident experienced drivers		Drivers without recent intersection accident experience	
Road users	38 (20)	95% (100%)	16	80%
Traffic signs	15 (7)	37.5% (35%)	9	45%
Traffic lights	11 (9)	27.5% (20%)	4	20%

Table 2: Distribution of frequencies of content card usage relating to dangerous situations

	Intersection accident experienced drivers		Drivers without recent intersection accident experience	
Information	12	30%	6	30%
Warning	34	85%	14	70%
Intervention	24	60%	13	65%
Emergency braking	10 (3)	25% (15%)	8	40%
Deceleration	18 (9)	45% (45%)	6	30%
Acceleration	9 (4)	22.5% (20%)	5	25%

Table 3: Frequencies of used concept cards concerning preferred levels of intersection assistance

In a further step the interviewees were asked about their opinion of effective intervention strategies. Multiple answers were possible. Most popular were strategies of deceleration: 25% of the drivers with, and 40% of the drivers without accident experience supported the strategy of emergency braking; 45% of the accident drivers and 30% of the non-accident drivers favoured early deceleration and 22.5% of the accident drivers as well as 25% of non-accident drivers approved of acceleration as an effective strategy of vehicle intervention. There were no noticeable differences between the matched samples. The results of the last two aspects are summarised in Table 3.

How should an intersection assistance system be designed to effectively assist the driver of a vehicle?

In order to answer this question it was discussed which warning strategies would be most effective in signalling the driver of an upcoming crash. The results are presented in Table 4 and 5. The results of the sample from Wolfsburg/Braunschweig are shown in brackets.

Warning/information	Acoustic		Visual		Tactile	
Used in structure	46	76.7%	34	56.7%	18	30%
Not used in structure	14	23.3%	26	43.3%	42	70%

Table 4: Frequencies of content card usage concerning warning strategies overview (n=60)

	Intersection accident experienced drivers		Drivers without recent intersection accident experience	
Audio warning	29 (14)	72.5% (70%)	5	25%
Acoustic output	15 (8)	37.5% (40%)	7	35%
Visual displays (Icons)	15 (10)	37.5% (50%)	7	35%
Head-up Display	8 (5)	20% (25%)	3	15%
Right-of-way-Display	5 (5)	12.5% (25%)	5	25%
Vibration seat/steering wheel	8 (4)	20% (20%)	6	30%
Vibration safety belt	8 (4)	20% (20%)	2	10%

Table 5: Frequencies of content card usage concerning warning strategies detailed

It can be seen that the participants favoured warning media that they had experienced in the vehicle context before. The 76.7% of the drivers who favoured acoustic warnings and information compared the audio warning with an acoustic parking system or the acoustic output with a navigation system. Furthermore 56.7% of the drivers suggested visual displays partly like those they are used to in their cars. In contrast there were only 30% of participants who liked the idea of vibrations for warning, for instance at the steering wheel, the seat or the safety belt. In conclusion audio warning strategies ($c\chi^2=4.543$; $p=0.045$) as well as visual warning strategies ($c\chi^2=4.667$; $p=0.046$) were preferred significantly to tactile warning strategies. It is notable that often combined strategies were suggested. So visual warnings were only preferred in combination with acoustic or tactile warnings

It is also evident by the sum of multiple answers given that the interviewees were open for different realizations of warnings in general. An interesting finding is the difference between the opinions of accident experienced drivers (72.5%) and non-accident experienced drivers (25%) concerning the approval of audio-warning strategies. Taking a look at the comparison of the matched samples using a binomial test procedure shows a significant difference between the group of accident experienced drivers and the group of drivers without accident experience in recent years (p=0.012).

Which factors are influencing the ideas and expectations of intersection assistance?

Since a lot of differences could not be found neither between the drivers with and without accident experience at intersections nor between the originators and non-originators of the accident one should look for other possible influencing factors on the structures of intersection assistance. The only variable which had significant effects on the structures of the participants was age and it is therefore discussed in this section.

Age is significantly correlated with the support of automatic vehicle intervention. The mean age of the drivers accepting automatic vehicle intervention is 42.3 years while the mean age of the drivers who disliked the idea of automatic vehicle intervention is 51.7 years ($n=60$; $T=2.145$; $p=0.036$). Age is also closely connected with the approval of the usage of head-up displays for visual warnings. Drivers who supported the idea have a mean age of 33.9 years in contrast to drivers who did not support the idea who were 48.6 years old ($n=60$; $T=3.583$; $p=0.002$).

Discussion

The results of the interviews about the experience of accident situations suggest that there are mainly mistakes of perception leading to crashes. Following the missing information perception the accident drivers did not have the possibility to avoid the accident through their own reaction. So if it was possible to provide an additional system which guides the information perception and focuses on critical situations with other road users, for example through an audio warning, many accidents in complex intersection situations could be prevented. Drivers could brake or steer evasively earlier and gain valuable time. Besides that, automatic systems which intervene immediately and correct could contribute to a reduction of accidents at intersections. When interpreting the open-minded attitude of the study's participants, effects of selective sample drawing of the accident drivers cannot be excluded. The participation in the study was voluntary and there is a possibility that the positive response behaviour of the accident drivers represents some kind of rehabilitation strategy.

Furthermore the findings indicate that drivers with accident experience at intersections are more convinced of audio warnings in their vehicles. Actually all participants mentioned audio and visual warning strategies more often than tactile warning strategies. This finding can also be interpreted as evidence for acquiring mental models dealing with certain products (KLUWE, 1992). The drivers are in a way already used to audio and visual warnings and have built associations between certain signals and dangers. It has to be evaluated which audio warnings are best for which kind of information. As an alternative to audio warnings some of the drivers preferred an acoustic output. The advantage of an acoustic output is that one does not even have to build associations between signals and dangers. On the other hand it could be easier to miss a warning, for example when talking to passengers of the car. Another argument against an acoustic output is the perception that it is too slow in critical situations. Before implementing new systems, advantages and disadvantages have to be researched carefully in experimental studies.

It is also remarkable that visual displays as a warning were supported only in combination with audio or tactile warnings. These results are probably due to the experience of the drivers, that it can take some time before noticing visual displays.

Warnings through tactile senses like vibration were used by the drivers significantly less in their structures. The reason for this finding could be the lower familiarity of the participants with this medium. An evidence for this statement is shown by the rationales of two young male participants for preferring vibrations at the steering wheel: they stated that they are used to these vibrations by using the game pad of their Play Station. Maybe this is a clue to individualize warning strategies in vehicles. Emergencies in vehicle driving are hopefully very rare. It might be a good solution to use existing stimulus-reaction-associations for a fast and effective warning in critical situations.

Two thirds of the interviewees approved of strategies for automatic vehicle intervention. Among those, some drivers supported sequential strategies of automatic vehicle interventions only after a warning and a chance for the driver to react himself. Others preferred immediate interventions of the vehicle. Often the drivers wished for additional information about the vehicles' actions. The results support the efforts of the automobile manufacturers in research of automatic braking strategies. It is also obvious that drivers feel less comfortable about acceleration strategies. This finding reflects the drivers' aversion to give up control over their vehicle. It is also relevant to the matter of take-over between the driver and the vehicle since acceleration raises the time pressure on the drivers which might lead to an increase of critical situations. These matters have to be researched intensively.

The findings of this study are useful in generating ideas for the development of intersection assistance. They inform about subjective opinions of the interviewed drivers about the effects of future products. Other aspects of the usability of an intersection assistant like interference with the driving task, operating convenience or actual efficiency have to be studied in the progress of the further development of intersection assistance systems (EN ISO 17287).

References

M. BONATO (1990): Wissensstrukturierung mittels Struktur-Lege-Techniken. Eine graphentheoretische Analyse von Wissensnetzen. Frankfurt am Main: Peter Lang

DIN EN ISO 17287 (2003): Ergonomische Aspekte von Fahrerinformations- und Fahrerassistenzsystemen. Verfahren zur Bewertung der Gebrauchstauglichkeit beim Führen eines Kraftfahrzeuges. Berlin: DIN Deutsches Institut für Normung e. V. (NormCD Stand 2004-03)

S. DUTKE (1994): Mentale Modelle: Konstrukte des Wissens und Verstehens. Göttingen: Verlag für Angewandte Psychologie

A. ENGELN, B .SCHLAG: Zur Entwicklungspsychologie des Verkehrsverhaltens – Der ältere Verkehrsteilnehmer. In: H.-P. KRÜGER (Hrsg.): Enzyklopädie der Psychologie – Verkehrspsychologie. Göttingen: Hogrefe

K. FELDMANN (1979): MEAP – Eine Methode zur Erfassung der Alltagstheorien. In: Bärbel SCHÖN & Klaus HURRELMANN (Hrsg.). Schulalltag und Empirie. Weinheim: Beltz

S. HEMMERLING (1998): Integration von Benutzererwartungen in die Konzeptphase des Produktentwicklungsprozesses. Sinzheim: Pro Universitate Verlag (ZMMS-Spektrum, Bd. 6)

R.H. KLUWE (1990): Gedächtnis und Wissen. In: H. SPADA. Lehrbuch der allgemeinen Psychologie (S. 115-187). Bern: Huber

J. REICHLE (1989): Verkehr Risikokompensation Schein und Haben. In: Auto, Motor und Sport, Vol. 9 (S. 274-280)

W.B. ROUSE, N. M. MORRIS (1986): On looking into the black box: Prospects and limits in the search for mental models. In: Psychological Bulletin, Vol. 100, No. 3 (S. 349-363)

P. SACHSE, W. HACKER (1995): Early Low Cost Prototyping (Forschungsberichte, Bd. 19). Institut für Allgemeine Psychologie und Methoden der Psychologie. Technische Universität Dresden

B. SCHEELE, N. GROEBEN (1988): Dialog-Konsens-Methoden zur Rekonstruktion subjektiver Theorien. Tübingen: Francke-Verlag

B. SCHLAG (1999): Empirische Verkehrspsychologie. Lengerich: Pabst Science Publishers

N. SEEL (1991): Weltwissen und mentale Modelle. Göttingen, Hogrefe

G. WELLER, B. SCHLAG (2004): Verhaltensadaptation nach Einführung von Fahrerassistenzsystemen: Vorstellung eines Modells und Ergebnisse einer Expertenbefragung. In: B. SCHLAG (Hrsg.): Verkehrspsychologie. Mobilität – Sicherheit – Fahrerassistenz. Lengerich: Pabst Science Publishers

Session:
Injury Prevention and Mechanism

H. Zwipp, R. Schubert, W. Schneiders

M. Richter, D. Otte, C. Haasper, K. Sommer, K. Knobloch, C. Probst, J. Westhoff, C. Krettek

K. Knobloch, S. Wagner, C. Haasper, C. Probst, C. Krettek, D. Otte, M. Richter

S. Rohrer, L. Hannawald, R. Koch, H. Zwipp

Y. Watanabe

J.S. Jermakian

W. Schneiders, A. Rollow, S. Rammelt, A. Biewener, M. Holch, A. Serra, S. Richter, B. Schlag, D. Roesner, H. Zwipp

H. Zwipp, R. Schubert, W. Schneiders
Department of Trauma and Reconstructive Surgery, Technical University Dresden, Germany

Injuries of Foot and Ankle in Front Seat Passengers

The number of injuries sustained by car occupants involving the head, thorax, spine, pelvis and the upper limbs have been reduced significantly during recent years. This is probably due to better safety features in the cars, especially the availability and usage of safety belts, airbags etc. Therefore one can notice clinically a relative increase in survivors of severe frontal crashes, but many of them have injuries to the lower extremities [1]. To verify this, we analyzed the foot and ankle injuries of front seat passengers.

Material and Methods

We analyzed all accidents registered by the Accidental Research Unit of the Technical University of Dresden from July 1999 to December 2002 with regard to foot and ankle injuries of front seat passengers of cars, buses and lorries.

Results

A total of 5.218 front seat passengers of four wheel vehicles were involved in accidents. 2.221 sustained an injury. 40 patients of 34 accidents sustained 49 foot/ankle injuries (AIS ≥2). The mean age was 41.7 years (17 to 75 years). There were 31 male and 9 female patients. The injured anatomic regions involved 19 ankle, 9 hindfoot, 7 midfoot and 14 forefoot fractures. The four anatomical groups were further analyzed and this showed that:

a) 19 fractures at the level of the ankle were simple fractures of the malleoli, 6 were severe fracture dislocations of the malleoli and 2 were pilon fractures.

b) 11 fractures of the hindfoot involved the calcaneus (n=5), talus (n=3), subtalar dislocation (n=2) and 1 severe hindfoot degloving injury.

c) 7 fractures of the midfoot were naviculare fractures (n=2), cuboid fracture (n=1), Chopart-fracture dislocations (n=3) and 1 subtotal amputation at the level of Chopart's line.

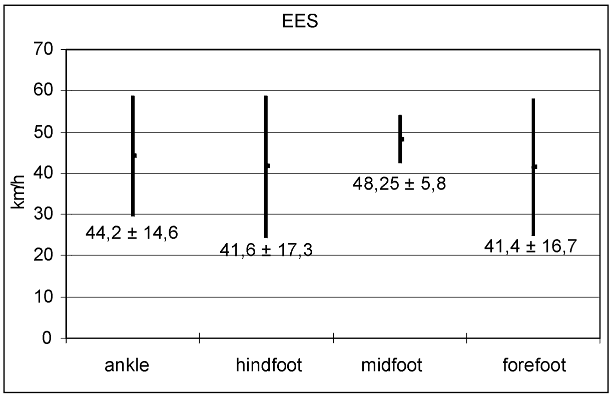


Figure 1: The 4 different anatomic levels of injured ankle and foot (n=49) show in comparison a slightly higher rate of Energy Equivalent Speed (EES) related to midfoot fractures

d) 14 fractures of the forefoot consisted of 13 fractures of the metatarsals and 1 open dislocation of MP 1-joint.

10 patients out of 40 were classified as polytraumas. 6 of them died at the scene of the accident or during transportation to the hospital. There were 4 open injuries. 4 patients broke both feet. The foot lying externally was more often injured than the one lying internally. Only 8 of 34 vehicles were equipped with an airbag, and it was deployed in 7 of 8 cases. 8 of 40 patients did not use the seat-belt. 24 accidents were frontal and 12 were offset crashes. There were no differences in speed changes (Δ_v) and in EES (Energy Equivalent Speed) between the injured foot regions. However in midfoot fractures (48.25 ±5.8km/h) as shown in Figure 1, we observed a tendency towards ankle and hindfoot injuries at level 20 to 40 EES and more forefoot injuries at higher EES between the levels of 40 to 60 EES. Midfoot fractures seemed to be mainly due to torque forces as a result of incarceration of the feet in between the pedals. Furthermore we noticed a tendency towards higher intrusion of the toepan in cases of hindfoot and midfoot fractures because of axial loading as compared with ankle and forefoot injuries (Figure 2). Foot and ankle fractures were seen in 27 drivers but only in 7 front seat passengers. 3 out of 20 injuries in vehicles with low intrusion were AIS II-injuries, but in cases of high intrusion we registered 7 out of 14 AIS III-injuries. There were no significant differences in speed changes Δ_v and EES between high and low intrusion events.

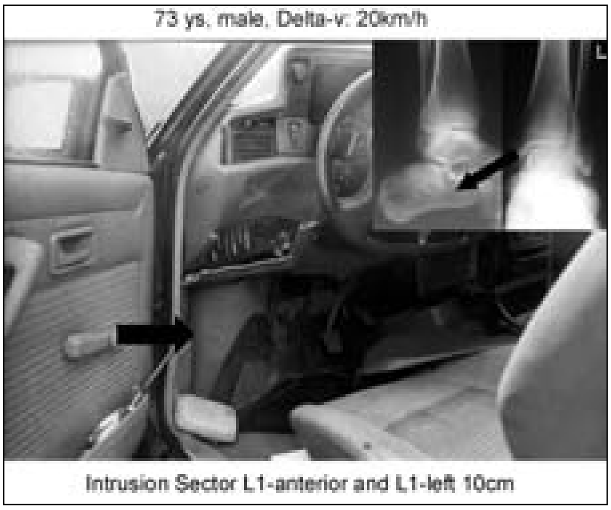


Figure 2: High intrusion of the toepan L1 left frontal of more than 10cm (see arrow)

Discussion

Foot and ankle fractures in vehicle passengers are uncommon but they often cause significant late disability [2]. Foot and ankle fractures occured four times more often in car drivers than in front seat passengers in our study. This was not seen in a previous study [3]. Therfore it is likely that besides intrusion of the toepan, impaction and the torque sustained by the feet in between the pedals significantly influences the dissipation of trauma energy.

Conclusion

Although foot injuries in car accidents are rare, there is a high incidence of late disability [3]. This has significant social-economic consequences. There is a need to stress technical improvements like stiffening the toepan or developing better alternatives to the mechanical pedals so as to prevent these injuries.

References

[1] P.C. DISCHINGER, T.J. KERNS, J.A. KUFERA (1995): Brief Communications and Research Notes. Lower Extremity Fractures in Motor Vehicle Collisions: The Role of Driver Gender and Height. Accid. Anal. and Prev., vol. 27, no. 4: 601-606

[2] G. REGEL, A. SEEKAMP, J. TAKACS, S. BAUCH, J.A. STURM, H. TSCHERNE (1993): Rehabilitation und Reintegration polytraumatisierter Patienten. Unfallchirurg 96:341-349

[3] M. RICHTER, H. THERMANN, H. von RHEINBABEN, E. SCHRATT, D. OTTE, H. ZWIPP, H. TSCHERNE (1999): Frakturen in der Fußregion bei Pkw-Insassen. Häufigkeit, Ursachen und Langzeitergebnisse. Unfallchirurg 102:429-433

M. Richter, D. Otte, C. Haasper, K. Sommer,
K. Knobloch, C. Probst, J. Westhoff, C. Krettek
Hannover Medical School, Hannover, Germany

The Current Injury Situation of Bicyclists – A Medical and Technical Accident Analysis

Abstract

Bicyclists are minimally or unprotected road users. Their vulnerability results in a high injury risk despite their relatively low own speed. However, the actual injury situation of bicyclists has not been investigated very well so far. The purpose of this study was to analyze the actual injury situation of bicyclists in Germany to create a basis for effective preventive measures.

Technical and medical data were prospectively collected shortly after the accident at the accident scenes and medical institutions providing care for the injured. Data of injured bicyclists from 1985 to 2003 were analyzed for the following parameters: collision opponent, collision type, collision speed (km/h), Abbreviated Injury Scale (AIS), Maximum AIS (MAIS), incidence of polytrauma (Injury Severity Score >16), incidence of death (death before end of first hospital stay).

4,264 injured bicyclists were included. 55% were male and 45% female. The age was grouped to preschool age in 0.9%, 6 to 12 years in 10.8%, 13 to 17 years in 10.4%, 18 to 64 years in 64.7%, and over 64 years in 13.2%. The MAIS was 1 in 78.8%, 2 in 17.0%, 3 in 3.0%, 4 in 0.6%, 5 in 0.4%, and 6 in 0.2%. The incidence of polytrauma was 0.9%, and the incidence of death was 0.5%. The incidence of injuries to different body regions was as follows: head, 47.8%; neck, 5.2%, thorax, 21%; upper extremities, 46.3%; abdomen, 5.8%; pelvis, 11.5%, lower extremities, 62.1%. The accident location was urban in 95.2%, and rural in 4.8%. The accidents happened during daylight in 82.4%, during night in 12.2%, and during dawn/dusk in 5.3%. The road situation was as follows: straight, 27.3%; bend, 3.0%; junction, 32.0%; crossing, 26.4%; gate, 5.9%; others, 5.4%. The collision opponents were cars in 65.8%, trucks in 7.2%, bicycles in 7.4%, standing objects in 8.8%, multiple objects in 4.3%, and others in 6.5%. The collision speed was grouped <31 in 77.9%, 31-50 in 4.9%, 51-70 in 3.7%, and >70 in 1.5%. The helmet use rate was 1.5%. 68% of the registered head injuries were located in the effective helmet protection area.

In bicyclists, head and extremities are at high risk for injuries. The helmet use rate is unsatisfactorily low. Remarkably, two thirds of the head injuries could have been prevented by helmets. Accidents are concentrated to crossings, junctions and gates. A significant lower mean injury severity was observed in victims using separate bicycle lanes. These results do strongly support the extension or addition of bicycle lanes and their consequent use. However, the lanes are frequently interrupted at crossings and junctions. This emphasizes also the important endangering of bicyclists coming from crossings, junctions and gates, i.e. all situations in which contact of bicyclists to motorized vehicles is possible. Redesigning junctions and bicycle traffic lanes to minimize the possibility of this dangerous contact would be preventive measures. A more consequent helmet use and use and an extension of bicycle paths for a better separation of bicyclists and motorized vehicle would be simple but very effective preventive measures.

Introduction

Bicyclists are minimally or unprotected road users [1, 2]. Their vulnerability results in a high injury risk despite their relatively low own speed [1, 2]. However, the actual injury situation of bicyclists has not been investigated very well so far [3-8]. Most of the previous studies analyzed medical, police, and/or insurance records [3-6, 9-24]. An in-depth analysis of the crash circumstances is missing in principle. Under consideration of the results of previous studies with other priorities, we strongly believe that a technical in-depth crash investigation in combination with a medical data analysis is the most sufficient basis for an improvement of passive safety [1, 2, 25-29]. The purpose of this study was to analyze the actual injury situation of bicyclists in Germany to create a basis for effective preventive measures.

Methods

Since 1972, a local traffic accident research unit has collected prospective data in regard to all reported traffic accidents within Germany [1, 25, 30, 31]. Specially trained documentation personnel are notified by police dispatchers and arrive on scene, often simultaneously with the rescue personnel. Thus, investigation of the accident (measurements by photography, stereophotography, 3D-Laser-technique), and clinical injury documentation are performed on site [1, 25, 30-32]. This case report is then completed at the hospital, where all of the injured victims are taken, with proper documentation of x-ray examination, injury type and severity.

Among the technical measurement techniques, especially the modern 3D-Laser-technique is a quick and exact method to document the exact position of all objects at the crash site [32]. A three-dimensional data cube with a maximum size of $50m^3$ is generated from the data obtained by the 3D-Laser-scanner. This data allows an exactly scaled reconstruction of the accident site for later technical analysis of the crash. Sliding and skidding marks of vehicles, objects and victims and any kind of deformation of involved vehicles or objects are also measured, and these data are included in the crash analysis. Furthermore, data from a database containing technical features of involved vehicles (size, weight, detailed structural data comparable to finite element analysis data) are included in the analysis [32]. The inclusion of the described data in a software based calculation allows an exact estimation of parameters as Delta-v or collision speed [32]. The collision speed, for example, is calculated by inclusion of the following data: deformation sites and deformation extents at the colliding under consideration of the exact structural data of that vehicle; deformation sites and deformation extents of the bicycle; sliding and skidding distances, and exact end positions of the involved vehicles, bicyclist and other objects [2, 30, 32, 33].

In total, the monitoring of the accident research unit includes demographic data, type of road user (car/truck occupant, motorcyclist, cyclist, pedestrian), delta-v (km/h) for motorized vehicle user; vehicle collision speed (km/h) for bicyclists/pedestrians, Abbreviated Injury Scale (AIS), Maximum AIS (MAIS), Injury Severity Score (ISS), incidence of serious and/or severe multiple injuries (polytrauma, ISS >16), incidence of serious injuries (MAIS 2-4) or severe injuries (MAIS 5/6), and mortality [34, 35].

For this study, traffic accident reports with dates from 1985 to 2003 from the local traffic research unit, as described above, were analyzed for the involvement of injured bicyclists as well as for the following parameters: demographic data, AIS, MAIS, ISS, incidence of polytrauma, incidence of serious or severe injuries, incidence of death, collision speed, collision opponent, and collision type. For statistical analysis of the correlation between crash circumstances with injury severity (AIS, MAIS, ISS) a t-, Pearson- or Linear-Trend-test was used.

The study was approved by the Ethical Commission of the Hannover Medical School, Hannover, Germany, and the State of Lower Saxony, Germany.

Results

4,264 injured bicyclists were analyzed.

Demographic data

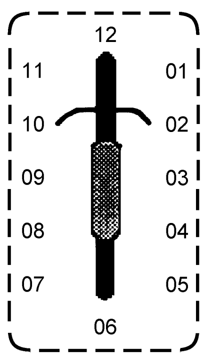
55% of bicyclists were male and 45% were female. The mean age of bicyclists was 52.0 (range, 4-83; standard deviation, 21.7) years. 0.9% were in preschool age, 10.8% were between 6 and 12 years old, 10.4% between 13 and 17, 64.7% between 18 and 64, and 13.2% were over 64 years old.

Crash circumstances

95.2% of accidents took place in urban areas, 4.8% in rural areas (Table 1). 55% of bicyclists used bicycle traffic lanes before the accident.

Road network location	
Straight	27.3%
Bend	3.0%
Junction	32.0%
Crossing	26.4%
Gate (junction to public road)	5.9%
Others	5.4%
Type of road	
Motorway	0.1%
Federal road	2.9%
Country road	6.6%
Street	68.4%
Parking lot	0.5%
Bicycle traffic lanes	16.8%
Playground	0.2%
Gate (accident located on gate)	1.2%
Others	3.3%

Table 1: Accident location in 4,264 injured bicyclists



1st impact	n	%
fall before	281	6,6
1 o'clock	119	2,8
2 o'clock	171	4
3 o'clock	516	12,1
4 o'clock	55	1,3
5 o'clock	55	1,3
6 o'clock	60	1,4
7 o'clock	81	1,9
8 o'clock	111	2,6
9 o'clock	849	19,9
10 o'clock	388	9,1
11 o'clock	303	7,1
12 o'clock	887	20,8
unknown	388	9,1

Figure 1: Direction of the first impact in 4,264 injured bicyclists

16.8% of crashes happened on bicycle traffic lanes. 82.5% of the accidents happened during daylight, 5.3% during dawn or dusk, and 12.2% during night or darkness. Collision opponents were cars in 65.8%, trucks in 7.2%, bicyclists in 7.4%, standing objects in 8.8%, multiple opponents or objects in 4.3%, and others in 6.5%. The mean collision speed was 21.3 (range, 0-123; standard deviation, 16.5)km/h. The collision speed amounted to less than 31km/h in 77.9%, between 31 and 50km/h in 4.9%, between 51 and 70km/h in 3.7% and above 70km/h in 1.5%. Figure 1 indicates the direction of the first impact at the victims' bicycles. 1.7% (n=78) of bicyclists were helmet protected.

Injuries

Table 2 indicates the MAIS and Table 3 the AIS of the different body regions. 79% of bicyclists sustained only injuries with minor severity (MAIS 1), and 4,2% at least one severe injury (MAIS 3+). The mean ISS was 3.87 (range, 1-75; standard deviation, 8.6). The incidence of polytrauma was 2.0% (n=84), and the incidence of death 1.5% (n=64). Fifty-eight victims (1.4%) died before reaching the medical institution, and six (0.1%) at a later stage during the initial hospital care. The lesions at the head in not helmet-protected bicyclists were located in 68% above the ear level, i.e. in the typical helmet protection area.

Correlation between crash circumstances and injury incidence and severity

A significant correlation of collision speed with AIS of all body regions, MAIS, and ISS occurred (Table 2, 3; Pearson-test <0.05). The collision speed was higher in victims with polytrauma or fatal injuries than in victims without (mean collision speed, polytrauma yes/no – 50.3/20.5km/h, t-test p<0.001; death yes/no – 52.3/20.8, t-test p<0.001).

Table 3 shows the incidence of injuries to the different body related to the impact speed of the opponent. The injury severity of nearly all the

	Collision speed (km/h)					
	in total (n=4,264)	<30 (n=3,321)	31-50 (n=209)	51-70 (n=158)	>70 (n=64)	unknown (n=511)
MAIS 1	78.8%	80.7%	66.5%	49.5%	33.7%	81.2%
MAIS 2	17.0%	16.5%	22.5%	29.5%	17.9%	15.6%
MAIS 3	3.0%	2.2%	7.2%	13.8%	15.7%	2.4%
MAIS 4	0.6%	0.3%	2.1%	3.4%	5.8%	0.5%
MAIS 5	0.4%	0.2%	1.5%	1.2%	15.7%	0.2%
MAIS 6	0.2%	0.1%	0.2%	2.5%	11.1%	0.0%

Table 2: MAIS and collision speed in 4,264 injured bicyclists

	Collision speed (km/h)				
	in total	<30	31-50	51-70	>70
Head					
not injured	53.2%	56.0%	35.8%	30.7%	18.0%
AIS 1	35.9%	34.9%	41.5%	31.4%	32.4%
AIS 2	9.3%	8.2%	18.0%	26.6%	15.8%
AIS 3+	1.6%	0.9%	4.7%	11.3%	33.8%
Neck					
not injured	95.6%	95.5%	95.4%	95.9%	87.6%
AIS 1	4.2%	4.3%	4.3%	2.9%	4.9%
AIS 2	0.1%	0.1%	0.2%	-	-
AIS 3+	0.1%	0.1%	0.1%	1.3%	7.5%
Thorax					
not injured	79.9%	80.7%	76.5%	65.3%	65.9%
AIS 1	16.1%	16.0%	14.8%	23.6%	7.3%
AIS 2	3.3%	3.0%	6.1%	7.0%	11.8%
AIS 3+	0.7%	0.4%	2.5%	4.1%	15.0%
Upper extremity					
not injured	54.2%	54.0%	53.3%	41.6%	30.8%
AIS 1	42.7%	43.2%	43.4%	53.6%	37.3%
AIS 2	2.7%	2.5%	2.8%	1.3%	18.6%
AIS 3+	0.3%	0.2%	0.6%	3.4%	13.3%
Abdomen not injured	95.1%	95.6%	89.7%	95.5%	82.8%
AIS 1	4.5%	4.1%	8.6%	2.8%	9.7%
AIS 2	0.2%	0.2%	1.1%	0.6%	-
AIS 3+	0.2%	0.2%	0.6%	1.1%	7.5%
Pelvis					
not injured	89.2%	90.2%	85.6%	89.8%	91.9%
AIS 1	10.2%	9.2%	12.6%	8.2%	1.1%
AIS 2	0.5%	0.3%	1.3%	1.4%	7.1%
AIS 3+	0.2%	0.2%	0.4%	0.6%	-
Lower extremity					
not injured	38.2%	37.4%	34.1%	25.0%	25.4%
AIS 1	56.0%	57.4%	55.7%	52.9%	44.1%
AIS 2	4.1%	3.9%	5.7%	11.0%	10.0%
AIS 3+	1.8%	1.3%	4.5%	11.1%	20.5%

Table 3: AIS of different body regions and collision speed in 4,264 injured bicyclists

	MAIS	ISS	Significance t-test
Helmet (n=78)	1.27±0.6	3.35±10.2	MAIS, p=0.02
No helmet (n=4,186)	1.46±0.8	3.97±8.7	ISS, p=0.05
Daylight (n=3,470)	1.43±0.8	3.82±8.6	MAIS, p=0.18
Darkness (n=537)	1.48±0.9	4.26±9.4	ISS, p=0.28
Urban (n=3,980)	1.41±0.9	3.60±7.8	MAIS, p<0.001
Rural (n=284)	1.83±1.1	7.6±15.0	ISS, p<0.001
Bicycle traffic lane used (n=2,348)	1.34±0.7	3.17±7.4	MAIS, p<0.001
No bicycle traffic lanes (n=1,916)	1.57±0.9	4.75±9.7	ISS, p<0.001
Road without junction etc. (n=1,339)	1.51±0.9	4.41±9.6	MAIS, p<0.001
Junction, crossing, gate etc. (n=2,910)	1.41±08	3.6±8.1	ISS, p=0.005

Table 4: Injury severity (MAIS, AIS, ISS) in different crash situations in 4,264 injured bicyclists. Mean values and standard deviations are indicated

different body regions was influenced by the impact speed, but especially head and lower extremity are at high risk in crashes with collision speed above 50km/h.

Table 4 shows the injury severity (MAIS, ISS) under different crash circumstances. Lower injury severity (MAIS, ISS) occurred in victims with a helmet, with crashes in urban areas and those who used bicycle lanes than in victims without helmet, crashes in rural areas and not using bicycle traffic lanes.

Discussion

In this study, a technical and medical in-depth investigation of more than 4,000 vehicular crashes with consequent injuries to bicyclists was performed. This study was focused on crash circumstances and epidemiologic data. Injury mechanisms were analyzed in further detail except an assessment of the bicycle helmet. The purpose of this analysis was to analyze the injury causes far beyond the numerous previous epidemiologic studies [3-6, 9-24].

In an earlier study, we demonstrated the high vulnerability to injury among the unprotected road users such as the pedestrians and bicycle users in children and adolescents [1]. The methodology of the data acquisition was discussed before [25, 26, 33, 36].

Special injury situation of bicyclists

In bicyclists, head and extremities are at high risk for injuries especially in high speed accidents (collision speed above 50km/h). Almost half of the injured bicyclists sustained head and/or upper extremity injuries, and almost two thirds sustained injuries of the lower extremities. These body regions are more endangered than in car occupants [1, 25, 27, 29]. Furthermore, a higher injury severity (ISS, MAIS) and mortality rates were seen in bicyclists.

The impact of head injuries is underlined by the high percentage of inpatient treatment among the group who sustained head injuries [37, 38]. A bicycle helmet has been shown to significantly decrease the risk and offer sufficient protection against head injuries [1]. Only 1.7% of the injured bicyclists were helmet protected in our study. This percentage was observed for the entire sample. Fortunately the helmet protection rate increased over the investigated period (data not shown). The helmet protection rate was higher for children than for adolescents and adults (data not shown). Approximately two thirds of the impact locations as witnessed on the heads of the bicycle victims had been in the areas that would have been protected with the use of a bicycle helmet. Consequently, mandatory regulations requiring bicycle helmet use would be a promising measure in the prevention of head injuries to bicyclists. Of course, only helmets fulfilling the Snell or ANSI standard would be adequate for the protection of injuries [24, 39-47].

The high percentage of lower extremity injuries as seen in collisions with cars demands further analysis of this type of crash scenario. The forces induced by the bumpers of cars and especially trucks, result in a high bending moment at the level of the knee and the proximal tibia. An alteration in design of vehicle bumpers with increased padding for example or with exterior airbags may reduce the frequency and/or severity of these injuries. Other promising preventive measures for the lower extremity are protective pads or clothes including pads as developed for motorcyclists [48]. In an earlier study, we demonstrated that protectors for motorcyclists could reduce the load to the tibia in bumper impacts sufficiently [48]. However, the acceptance of bicyclists' additional pads or clothes is at least as problematic as of helmets [1, 48].

Another important factor is speed, since the injury severity is increasing rapidly at collision speeds above 50km/h. Additional speed limits in areas with "bicycle traffic" should be considered as a useful measure to reduce injury severity in bicyclists.

A significant lower mean injury severity was observed in victims using separate bicycle lanes. These results do strongly support the extension or addition of bicycle lanes and their consequent use. However, the lanes are frequently interrupted at crossings and junctions. This explains why more than two thirds of the bicyclists that had used bicycle lanes before crash were then involved in a crash out of the bicycle lane. This emphasizes also the important endangering of bicyclists coming from crossings, junctions and gates, i.e. all situations in which contact of bicyclists to motorized vehicles is possible. Redesigning junctions and bicycle traffic lanes to minimize the possibility of this dangerous contact would be preventive measures.

In conclusion, in bicyclists, head and extremities are at high risk for injuries. The helmet use rate is unsatisfactorily low. Remarkably, two thirds of the head injuries could have been prevented by helmets. Accidents are concentrated to crossings, junctions and gates.

A more consequent helmet use and use and an extension of bicycle traffic lanes for a better separation of bicyclists and motorized vehicle would be simple but very effective preventive measures.

Acknowledgements

The authors thank Birgitt WIESE, PhD (Institute for Biometry, Hannover Medical School, Hannover, Germany) for her help and support in carrying out the statistical analysis and for her unbiased prior evaluation, and Justin BENDER, PhD for the critical review of the manuscript and the extensive language editing.

References

[1] M. RICHTER, D. OTTE, H.C. PAPE et al.: Current Situation of Road Traffic Accidents in Infants and Adolescents – A Medical and Technical Analysis. J Orthop Trauma. 2002;16:70-71

[2] M. RICHTER, H.C. PAPE, D. OTTE et al.: The current status of road user injuries among the elderly in Germany: a medical and technical accident analysis. J Trauma. 2005;58:591-595

[3] S.J. ASHBAUGH, M.L. MacKNIN, M.S. VANDERBRUG: The Ohio Bicycle Injury Study. Clin Pediatr (Phila). 1995;34:256-260

[4] S. LINN, D .SMITH, S. SHEPS: Epidemiology of bicycle injury, head injury, and helmet use among children in British Columbia: a five year descriptive study. Canadian Hospitals Injury, Reporting and Prevention Program (CHIRPP). Inj Prev. 1998;4:122-125

[5] H.W. ORTEGA, B.J. SHIELDS, G.A. SMITH: Bicycle-related injuries to children and parental attitudes regarding bicycle safety. Clin Pediatr (Phila). 2004;43:251-259

[6] B.H. ROWE, A.M. ROWE, G.W. BOTA:. Bicyclist and environmental factors associated with fatal bicycle-related trauma in Ontario. CMAJ. 1995;152:45-53

[7] D. OTTE: A review of different kinematic forms in two wheel accidents – their influence on injuries and effectiveness for protective measures. SAE Transaction 801314, Detroit, USA , 561-605. 1980.

[8] D. OTTE, E.G. SUREN: Der Fahrradunfall – Eine verkehrsmedizinisch-technische Analyse. Heidelberg: 1986

[9] E. MISSONI, J. KERN: Fatality risk factors for bicyclists in Croatia. Croat Med J. 2003;44:610-613

[10] E.K. MOLL, A.J. DONOGHUE, E.R. ALPERN et al.: Child bicyclist injuries: are we obtaining enough information in the emergency department chart? Inj Prev. 2002;8:165-169

[11] F.K. WINSTON, J. POSNER, E. ALPERN et al.: Who can give a pediatric trauma history for children injured in bicycle crashes? Annu Proc Assoc Adv Automot Med. 2000;44: 459-69

[12] .PK. DHILLON, A.S. LIGHTSTONE, C. PEEK-ASA et al.: Assessment of hospital and police ascertainment of automobile versus childhood pedestrian and bicyclist collisions. Accid Anal Prev. 2001;33:529-537

[13] R. EKMAN, G. WELANDER, L. SVANSTROM et al.: Bicycle-related injuries among the elderly – a new epidemic? Public Health. 2001;115:38-43

[14] J.C. STUTTS, W.W. HUNTER: Motor vehicle and roadway factors in pedestrian and bicyclist injuries: an examination based on emergency department data. Accid Anal Prev. 1999;31:505-514

[15] M.S. DURKIN, D. LARAQUE, I. LUBMAN et al.: Epidemiology and prevention of traffic injuries to urban children and adolescents. Pediatrics. 1999;103:e74

[16] G. LI, S.P. BAKER: Injuries to bicyclists in Wuhan, People's Republic of China. Am J Public Health. 1997;87:1049-1052

[17] C. FARRIS, D.W. SPAITE, E.A. CRISS et al.: Observational evaluation of compliance with traffic regulations among helmeted and nonhelmeted bicyclists. Ann Emerg Med. 1997;29:625-629

[18] B. YTTERSTAD: The Harstad injury prevention study: hospital-based injury recording used for outcome evaluation of community-based prevention of bicyclist and pedestrian injury. Scand J Prim Health Care. 1995;13:141-149

[19] G.B. RODGERS: Bicyclist deaths and fatality risk patterns. Accid Anal Prev. 1995;27:215-223

[20] F.P. RIVARA, R.V. MAIER, B.A. MUELLER et al.: Evaluation of potentially preventable deaths among pedestrian and bicyclist fatalities. JAMA. 1989;261:566-570

[21] S.M. SELBST, D. ALEXANDER, R. RUDDY: Bicycle-related injuries. Am J Dis Child. 1987;141:140-144

[22] K.S. HANSEN, G.E. EIDE, E. OMENAAS et al.: Bicycle-related injuries among young children related to age at debut of cycling. Accid Anal Prev. 2005;37:71-75

[23] A. COOK, A .SHEIKH: Trends in serious head injuries among English cyclists and pedestrians. Inj Prev. 2003;9:266-267

[24] G.W. PARKINSON, K.E. HIKE: Bicycle helmet assessment during well visits reveals severe shortcomings in condition and fit. Pediatrics. 2003;112:320-323

[25] M. RICHTER, H. THERMANN, B. WIPPERMANN et al.: Foot fractures in restrained front seat car occupants: a long-term study over twenty-three years. J Orthop Trauma. 2001;15:287-293

[26] M. RICHTER, D .OTTE, K. JAHANYARET et al.: Upper Extremity Fractures in Restrained Front Occupants. J Trauma. 2000;48:907-912

[27] M. RICHTER, D. OTTE, A. GANSSLEN et al.: Injuries of the pelvic ring in road traffic accidents: a medical and technical analysis. Injury. 2001;32:123-128

[28] M. RICHTER, R. FERRARI, D. OTTE et al.: Correlation of clinical findings, collision parameters, and psychological factors in the outcome of whiplash associated disorders. J Neurol Neurosurg Psychiatry. 2004;75:758-764

[29] M. RICHTER, H.C. PAPE, D. OTTE et al.: Improvements in passive car safety led to decreased injury severity – a comparison between the 1970s and 1990s. Injury. 2005; 36:484-488

[30] D. OTTE: The Accident Research Unit as Example for Importance and Benefit of Existing In-Depth Investigations. SAE Paper 940712 Detroit USA. 1994

[31] D. OTTE, C. KRETTEK, H. BRUNNER et al.: Scientific Approach and Methodology of a New In-depth Investigation Study in Germany so called GIDAS. ESV paper-, Nagoya/Japan, Mai 2003, 2003

[32] D. OTTE: 3-D-Laser Systems for scaled accident sketches and documentation of traces after accidents asa basis of biomechanical analysis. IRCOBI Conference Prague. 2005

[33] M. RICHTER, D. OTTE, U. LEHMANN et al.: Head injury mechanisms in helmet-protected motorcyclists: prospective multicenter study. J Trauma. 2001;51:949-958

[34] American Association for Automotive Medicine: Abbreviated Injury Scale – Revision 90. Am Ass F Autom Med, Morton Grove, Illinois, USA. 1995

[35] S.T. BAKER, B. O'NEILL, W. HEDDON et al.: The Injury Severity Score: A method for describing patients with multiple injuries and evaluating emergency care. J Trauma. 1974;14:187-195

[36] M. RICHTER, C. KRETTEK, D. OTTE et al.: Correlation between crash severity, injury severity, and clinical course in car occupants with thoracic trauma: a technical and medical study. J Trauma. 2001;51:10-16

[37] S. KILARU, J. GARB, T. EMHOFF et al.: Long-term functional status and mortality of elderly patients with severe closed head injuries. J Trauma. 1996;41:957-963

[38] R.M. SAYWELL, J.R. WOODS Jr., S.A. RAPPAPORT et al.: The value of age and severity as predictors of costs in geriatric head trauma patients. J Am Geriatr Soc. 1989;37:625-630

[39] M. WILLIAMS: The protective performance of bicyclists' helmets in accidents. Accid Anal Prev. 1991;23:119-131

[40] F.T. McDERMOTT: Bicyclist head injury prevention by helmets and mandatory wearing legislation in Victoria, Australia. Ann R Coll Surg Engl. 1995;77:38-44

[41] F.T. McDERMOTTT, J.C. LANE, G.A. BRAZENOR et al.: The effectiveness of bicyclist helmets: a study of 1,710 casualties. J Trauma. 1993;34:834-844

[42] F.T. McDERMOTT: Helmet efficacy in the prevention of bicyclist head injuries: Royal Australasian College of Surgeons initiatives in the introduction of compulsory safety helmet wearing in Victoria, Australia. World J Surg. 1992;16:379-383

[43] B.H. LEE, J.L. SCHOFER, F.S. KOPPELMAN: Bicycle safety helmet legislation and bicycle-related non-fatal injuries in California. Accid Anal Prev. 2005;37:93-102

[44] C. FARLEY, L. LAFLAMME, M. VAEZ: Bicycle helmet campaigns and head injuries among children. Does poverty matter? J Epidemiol Community Health. 2003;57:668-672

[45] L.F. NOVICK, M. WOJTOWYCZ, G.B. MORROW et al.: Bicycle helmet effectiveness in preventing injury and death. Am J Prev Med. 2003;24:143-149

[46] W.J. CURNOW: The efficacy of bicycle helmets against brain injury. Accid Anal Prev. 2003;35:287-292

[47] A.K. MacPHERSON, C. MacARTHUR: Bicycle helmet legislation: evidence for effectiveness. Pediatr Res. 2002;52:472

[48] D. OTTE, G. SCHROEDER, M. RICHTER: Possibilities for load reductions using garment leg protectors for motorcyclists – a technical, medical and biomechanical approach. Annu Proc Assoc Adv Automot Med. 2002;46:367-85

K. Knobloch, S. Wagner, C. Haasper, C. Probst, C. Krettek, M. Richter
Trauma Department, Medical School Hannover, Germany

D. Otte
Accident Research Unit, Medical School Hannover, Germany

Sternal Fractures Occur Most Often in Old Cars to Seat-Belted Drivers without any Airbag Often with Concomitant Spinal Injuries – Clinical Findings and Technical Collision Parameters among 42.055 Crash Victims

Abstract

The incidence and treatment of sternal fractures among traffic accidents are of increasing importance to ensure best possible outcomes.

Analysis of technical indicators of the collision, preclinical and clinical data of patients with sternal fractures from 1985-2004 among 42,055 injured patients were assessed by an Accident Research Unit. Two time groups were categorized: 1985-1994 (A) vs. 1995-2004 (B).

267/42,055 patients (0.64%) suffered a sternal fracture. Regarding the vehicle type, the majority occurred after car accidents in 0.81% (251/31,183 pts), followed by 0.19% (5/2,633pts) driving motorbike, and 0.11% (4/3,258pts) driving a truck. 91% wore a safety belt. Only 13% of all passengers suffering a sternal fracture had an airbag on board (33/255 car/trucks), with an airbag malfunction in 18%. The steering column was deformed in 39%, the steering wheel in 36%. Cars in the recent years were significantly older (7.67±5 years (B) vs. 5.88±5 years (A), p=0.003). Cervical spine injuries are frequent (23% vs. 22%), followed by multiple rib fractures (14% vs. 12%) and lung injuries (12% vs. 11%). We found 9/146 (6%) and 3/121 patients (3%) with heart contusion among the 267 sternal fractures. MAIS was 2.56±1.3 vs. 2.62±1.3 (A vs. B, p=0.349). 18% of patients were polytraumatized, with 11.2% dying at the scene, 2.3% in the hospital.

Sternal fractures occur most often in old cars to seat-belted drivers often without any airbag. Severe multiple rib fractures and lung contusion are concomitant injuries in more than 10% each indicating the severity of the crash. Over a twenty-year period, the injury severity encountered was not different with 18% polytrauma patients suffering sternal fractures.

Introduction

Throughout the last decades, the rate of sternal fractures has increased due to the introduction of seat-belts [1] in cars and trucks as well as by further thorough clinical investigations in the emergency room using sternal sonography [2] and thoracic computertomography [3] (CT) after traffic accidents. The role of airbags in reducing thoracic injuries is still debated controversely [4, 5].

Among 200 sternal fractures [6] with predominant traffic accidents (83%), 179 sternal fractures were located in the corpus sterni, 21 fractures in the manubrium sterni, and 11 in the xiphoid process. Another study supported the predominant location of the sternum body (83%), followed by 11% manubrium sterni and 6% xiphoid fractures among 100 patients [7]. While 67% of these patients had isolated sternal fractures, one third had concomitant injuries. Rib fractures have been reported in 28% without any clarification regarding the number of ribs involved, cardiac injury as hemopericardium was encountered in 1%.

FOWLER [8] found that 43% of sternal fractures were associated with a spinal injury. Other reports are limited due to small sample groups, with one study of blunt trauma by HILLS [9] reporting that out of 27 patients with thoracic spine fractures, five had associated sternal fractures. BROOKES showed 4.8% incidence of thoracic spine fractures in patients with sternal fractures [10]. In a retrospective study between 1981 and 1987, JONES [11] discovered eight patients with indirect sternal fractures and concomitant fractures of the spine (5 thoracic and 3 lumbar).

However, the evidence regarding concomitant multiple rib fractures as well as lung contusion associated with sternal fractures is limited. Furthermore, to date no thorough information is available regarding the circumstances of collisions causing a sternal fracture in traffic accidents. A technical analysis of the accident scene and the vehicle are pending. We therefore performed a thorough analysis among 20 years of accident research in a given regional area around Hannover in Germany with special emphasis regarding to technical accident analysis as well as to clinical information and outcome among 267 patients suffering a sternal fracture among 42,055 injured and documented patients from 1985-2004 in a rural area around Hannover, Germany.

Methods

In a statistical retrospective analysis of car collision files from January 1st, 1985 to December 31st, 2004, the incidence and mechanism of 267 sternal fractures among a total number of 42.055 injured patients involved in a vehicle accident were examined. Regarding the data used from this governmental database, local ethical committee agreed to use the data without the individual consent of each patient, all data were used anonymously. The accident files had been prepared by scientific teams of the Accident Research Unit, which is run by the government. The teams had been informed through police dispatch and quickly arrived at the accident scenes in their own squad vehicles.

Since 1972, this local traffic accident research unit has collected prospective data for all reported traffic accidents in the rural area of Hannover, Germany [12]. The Accident Research Unit is alarmed randomly on every third traffic accident with casualties regardless of the type of injury, number of injured patients or severity of injuries. In addition to technical indications and an evaluation of the damage to the car, the files also included medical records outlining the types and severity of the injuries to the occupants. Seat-belt use was determined by history or assessment of the injury pattern. The first medical institution providing care for the injured people documented the diagnosis and types of injury. Pictures of the vehicular collision scene and the inside and outside of the cars and the relevant radiographs were collected by the staff of the Accident Research Unit.

Through this database, we were able to reconstruct the injury mechanisms in detail. This reconstruction was performed by the staff of the Accident Research Unit under the direction of the technical author (D.O.). The injury severity was classified with the abbreviated injury scale (AIS). These classifications were performed by the staff of the Accident Research Unit. To estimate the relevance of the improvements of the passive car safety and any change over time, accidents occurring from January 1st, 1985 to December 31st, 1994 (Group I) and from January 1st, 1995 to December 31st, 2004 (Group II) were compared.

Statistics

The data is presented as median and range for continuous variables or number and percentages for dichotomous variables. Median values were displayed for the percent change of parameters of microcirculation. Univariate analysis of categorical data was carried out using the chi-square or Fisher exact tests. Univariate analysis of metrical data was carried out by one way ANOVA, Student´s t-test and Mann-Whitney-U-Test. Student´s t-test for paired-samples was used for parametric, ordinal and metrical variables of connected samples. The SPSS statistical software package 11.5 for Windows (SPSS Inc., Chicago, Ill, USA) was used for statistical analysis.

Results

42,055 injured patients were included in this study from 1985-2004, where technical and medical information was available for assessment. 267 patients suffered a sternal fracture, while 41,788 patients were injured in a traffic accident and assessed without a sternal fracture (0.64%). The distribution regarding the type of vehicle in sternal fractures is displayed in Table 1, demonstrating cars as the main vehicle involved in sternal fractures.

Type of vehicle	Total	No sternal fracture	Sternal fracture	% sternal fracture
Car	31,183	30,932	251	0.81%
Truck	3,258	3,524	4	0.11%
Motorbike	2,633	2,628	5	0.19%
Bicycle	4,971	4,965	6	0.12%
Others	10	9	1	10.00%
Total	42,055	41,788	267	0.64%

Table 1: Distribution of 42,055 injured patients assessed over a 20-year period (1985-2004) in the region of Hannover, Germany, regarding the vehicle type among sternal fractures

Safety-belt and airbag in patients suffering sternal fractures

91.2% of all patients wore a safety belt at the time of the accident. Only 13% of all passengers injured with a sternal fracture had an airbag on board (33/255 patients driving cars or trucks). Among those 33 patients with an airbag on board, a malfunction of the airbag was evident in 6/33 (18.2%). Side airbags at the top were only in 1% of the vehicle without any activation during the accidents at all. Due to the small sample size of only 33 cases with airbags on board, we did not attempt to determine any effect of time over the studied twenty-year period in this study.

Seating position of patients suffering sternal fractures

65.4% of all car passengers were seated at the driver's position, 26.7% at the front right position. 92.1% of all patients suffering a sternal fracture were therefore seated in the front row.

Crash vehicle characteristics

Cars in the recent years between 1995 and 2004 were significantly older than in between 1985 and 1994 (7.67±5 years (B) vs. 5.88±5 years (A), p=0.003) with patients suffering sternal fractures. The majority of crashes were head-on crashes into another vehicle, followed by crashes by leaving the road, crossing vehicle crashes and rear-end crashes, as indicated in Table 2.

Patients trapped in the vehicle suffering sternal fractures

Among the patients suffering a sternal fracture, we found 10% (26/250 car/truck patients) trapped in the car/truck at the scene needing technical rescue by the fire department.

Polytrauma and Glasgow coma scale at the scene among patients with sternal fractures

47/267 patients (17.6%) were classified as polytraumatized, where at least one or the combination of more injuries was supposed to be life threatening. Mean Glasgow coma scale (GCS) at the scene was 13.1±4: 85.1% (n=223) were GCS 11-15, 1.9% (n=5) were GCS 6-10, 13% (n=34) were GCS<5.

Concomitant injuries in 267 patients with sternal fractures

The major concomitant injury associated with sternal fractures were bruises of soft tissue with 84/146 cases (57.5%) in 1985-94 and 65/121 cases (53.7%) in 1995-2004 (Table 3). The second frequent concomitant injury to sternal fractures were spine injuries with 47/146 (32.2%) and 32/121 (26.5%), respectively. Regarding spine injuries, the cervical spine was most often involved (22.6% vs. 22.3%) with distortions predominantly. There was no change in the frequency of cervical spine injuries over the 20-year observation period. Injuries of the thoracic spine followed the cervical spine injuries without any change over time (9.6% vs. 8.3%), but thoracic spine injuries were almost all fractures. Lumbar spine injuries accounted for 4.8% and 1.7% as a concomitant injury to sternal fractures with lumbar fractures being often encountered.

Vehicle crased	1985-1994		1995-2004	
	n (∑=146)	percentage of known cases	n (∑=121)	percentage of known cases
Rear-end crash	23	17.9%	22	18.3%
Head-on crash	48	37.5%	44	36.6%
Crossing car crash	25	19.5%	20	16.7%
Crash w/o other car by leaving the road	28	21.8%	34	27.5%
By another way	4	3.1%	1	0.8%
Unknown	18		1	

Table 2: Crash circumstance among 267 sternal fractures suffering an accident over a 20-year period in the region of Hannover, Germany

Injury	1985-1994		1995-2004	
	n (∑=146)	percentage of known cases	n (∑=121)	percentage of known cases
Bruise of soft tissues	84	58%	65	54%
Brain injury	41	28%	22	18%
Multiple rib fracture	20	14%	15	12%
Injury of lungs	18	12%	13	11%
Injury of heart	9	6%	3	2%
Injury of spine overall	47	32%	32	26%
Injury of cervical spine	33	23%	27	22%
Injury of thoracic spine	14	10%	10	8%
Injury of lumbar spine	7	5%	2	2%

Table 3: Concomitant injuries among 267 sternal fractures in regard to the time periods 1985-94 and 1995-2004 in Hannover, Germany, among 42,055 injured patients

Following bruises and spinal injuries head injuries were found third as concomitant injury among the 267 sternal fractures (28% vs. 18%), followed by multiple rib fractures (13.7% vs. 12.4%) and lung injuries (12.3% vs. 10.7%). We found 9/146 patients (6.2%, 1985-94) and 3/121 patients (2.5%, 1995-2004) with myocardial contusions among the 267 sternal fractures.

Abbreviated injury scale (AIS)

Maximal abbreviated injury scale (MAIS) was at mean 2.56±1.3 in 1985-1994 and 2.62±1.3 from 1995-2004 (p=0.349). Mean AIS chest was 2.5±1.1 in 1985-94 vs. 2.5±1 in 1995-2004 without a statistical difference over time (p=0.451). The distribution was aS followed: AIS 0 none, AIS 1 5/146 patients (3.4%) vs. 3/121 patients (2.5%), AIS 2 109/146 patients (75.2%) vs. 89/121 patients (74.8%), AIS 3 12/146 patients (8.3%) vs. 6/121 (5%), AIS 4 6/146 patients (4.1%) vs. 13/121 patients (10.9%), AIS 5 4/146 patients (2.8%) vs. 4/121 patients (3.4%), AIS 6 9/146 patients (6.2%) vs. 4/121 patients (3.4%). Mean AIS for the head injury was 1.2±1.6 (1985-94) vs. 1.0±1.4 (1995-2004) without any statistical change over time (p=0.135). Distribution of head AIS was aS followed: AIS 0 72/146 patients (49.3%, 1985-94) vs. 65/121 patients (55.6%, 1995-2004), AIS 1 27/146 (18.5%) vs. 22/121 (18.8%), AIS 2 29/146 (19.9%) vs. 17/121 (14.5%), AIS 3 3/146 (2.1%) vs. 4/121 (3.4%), AIS 4 6/146 (4.1%) vs. 4/121 (3.4%), AIS 5 2/146 (1.4%) vs.2/121 (1.7%), and AIS 6 7/146 (4.8%) vs. 3/121 (2.6%).

AIS for the thorax/shoulder injury was on average 2.47±1.1. Categorized, 75% of all 267 patients suffering a sternal fracture were AIS 2 (Tables 4). AIS arms was 0.5±0.8 vs. 0.6±0.8 (p=0.312). 97/146 patients (66.9%, 1985-94) vs. 75/121 patients (62%, 1995-2004) were rated AIS arms 0, the highest scores were AIS 3 with 9/146 (6.2%, 1985-94) vs. 4/121 (3.3%, 1995-2004). AIS abdomen was 0.62±1.5 in 1985-94 and 0.29±1 in 1995-2004, which was significantly decreased over time (p=0.016). 81.4% (118/146 patients) vs. 89.5% (102/121) were AIS 0. While 12/146 (8.3%) were AIS 5 in 1985-94, no one was AIS 5 in 1995-2004.

Hemodynamics at admission in the emergency room

At hospital admission in the emergency room, mean systolic blood pressure was 130±29mmHg with a corresponding heart rate OF 89±8bpm. 89.5% had regular and normfrequent heart rate at ER admission, 5.7% had tachycardia, 2.6% (n=6) had asystole. At ER admission 5.6% were mechanically ventilated.

AIS chest/shoulder				
AIS chest / shoulder	1985-1994		1995-2004	
	n (∑=146)	percentage of known cases	n (∑=121)	percentage of known cases
0	0	0.0%	0	0.0%
1	5	3.4%	3	2.5%
2	109	75.2%	89	74.8%
3	12	8.3%	6	5.0%
4	6	4.1%	13	10.9%
5	4	2.8%	4	3.4%
6	9	6.2%	4	3.4%
unknown	1		2	
mean	2.5 ±1.1		2.5 ±1.1	
α=0.451				
AIS abdomen				
AIS abdomen	1985-1994		1995-2004	
	n (∑=146)	percentage of known cases	n (∑=121)	percentage of known cases
0	118	81.4%	102	89.5%
1	7	4.8%	2	1.8%
2	3	2.1%	5	4.4%
3	3	2.1%	1	0.9%
4	2	1.4%	3	2.6%
5	12	8.3%	0	0.0%
6	0	0.0%	1	0.9%
unknown	1		7	
mean	0.6 ±1.5		0.3 ±1	
α=0.016				
AIS head				
AIS head	1985-1994		1995-2004	
	n (∑=146)	percentage of known cases	n (∑=121)	percentage of known cases
0	72	49.3%	65	55.6%
1	27	18.5%	22	18.8%
2	29	19.9%	17	14.5%
3	3	2.1%	4	3.4%
4	6	4.1%	4	3.4%
5	2	1.4%	2	1.7%
6	7	4.8%	3	2.6%
unknown	0		4	
mean	1.2 ±1.6		1.0 ±1.4	
α=0.135				

Table 4: Abbreviated injury scale (AIS) for the chest, the abdomen and the head among 42,055 patients with 267 sternal fractures over a 20-year period in the region of Hannover, Germany

Procedures performed in the hospital

195/267 patients suffering a sternal fracture had no operation at all during the hospital stay (79.6%). 12.7% were operated within the first 24 hours of admission, 2% within the 2nd to the 7th hospital day.

Hospital stay and ICU stay

Hospital stay was on average 9.7±16.5 days, with 18.7% being on an outpatient basis (n=29), 11% admitted for 48 hours (n=17), 22.6% admitted from 3 to 5 days (n=35), 25.8% for 6 to 10 days (n=40), and 21.9% for more than 10 days (n=34). Among 121 patients, 5% were up to 48h admitted to the ICU (n=6), 4.1% 3 to 5 days (n=5), 1.7% for 6 to 10 days (n=2) and 5% were longer than 10 days on the ICU (n=6, Table 5).

duration	1985-1994		1995-2004	
	n (∑=146)	percentage of known cases	n (∑=121)	percentage of known cases
0 days	83	88%	20	71%
< 3 days	3	3%	3	11%
3 - 5 days	2	2%	3	11%
6 - 10 days	2	2%	0	0%
> 10 days	4	4%	2	7%
Unknown	52		93	
Mean	1.7 ±7.4		2.7 ±8.1	
α=0.280				

Table 5: Days on the intensive care unit among 267 sternal fractures among 42,055 injured patients over a 20-year period

Vertebra	Total		Fracture		Distorsion		Others	
	1985-1994	1995-2004	1985-1994	1995-2004	1985-1994	1995-2004	1985-1994	1995-2004
C1								
C2		2		2				
C3		2		2				
C4								
C5	2	1	1	1			1	
C6	5		2		2		1	
C7								
Cervical spine w/o further details	35	26		1	35	22		3
TH1	3		3					
TH2								
TH3		1		1				
TH4		1		1				
TH5	2	2	2	2				
TH6	2	2	2	2				
TH7	1	2	1	2				
TH8	2	1	2	1				
TH9	1	1	1	1				
TH10	1		1					
TH11								
TH12								
Thoracic spine w/o further details	4	5		2	4	2		1
L1	1		1					
L2								
L3	1		1					
L4	1		1					
L5		1		1				
Lumbal w/o further details	6	1	2		2	1	2	
Total	67	48	20	19	37	22	4	4
Note: Every count represents an injury of the vertebra shown in the first column. As one person may have more than one injured vertebra, there is no correlation given between the number of injured vertebras in this table and the number of persons having an injury at their spine								

Table 6: Distribution of concomitant spinal injuries in 267 sternal fractures

	ΔV mean 1985-1994 [km/h]	ΔV mean 1995-2004 [km/h]	ΔV mean total [km/h]
no polytrauma	37,94 ± 15,40	36,75 ± 16,81	37,43 ± 16,03
polytrauma	62,77 ± 15,78	58,00 ± 16,73	60,07 ± 16,49
overall	40,60 ± 17,25	40,44 ± 18,62	40,53 ± 17,88
p [t-test]	0,00000014	0,0000045	0,0000000000076
Correlation between survival andΔV by 219 victims of car-crashes			
	ΔV mean 1985-1994 [km/h]	ΔV mean 1995-2004 [km/h]	ΔV mean total [km/h]
survived	39,10 ± 16,02	37,07 ± 16,90	38,24 ± 16,43
died	65,14 ± 17,98	59,07 ± 16,63	61,00 ± 17,30
overall	40,60 ± 17,25	40,44 ± 18,62	40,53 ± 17,88
p [t-test]	0,000037	0,0000064	0,0000000024

Table 7: Correlation among patients suffering a polytrauma or not and ΔV among 219 victims of car crashes

Survival

230/267 patients (86.1%) suffering sternal fractures survived the accident and the hospital, 30/267 patients (11.2%) died at the scene. One patient with a sternal fracture died on the transport to the hospital, 6 further patients died within the hospital (2.3%). Among those patients dying at the scene, 43% had fatal head injuries, 32% had fatal thoracic injuries (n=37).

Discussion

Sternal fractures occur most often in old cars to seat-belted drivers. Severe multiple rib fractures and lung contusion are concomitant injuries in more than 10% indicating the severity of the crash. 18% of all patients suffering a sternal fracture were classified as polytrauma patients with an overall survival rate of 86.1%. While 11.2% die at the scene, we found a 30-day mortality of 2.3%.

These data reveal that sternal fractures often are associated with concomitant significant injuries and a remarkable mortality rate. The high mortality rate found in our study may indicate that a sternal fracture could be interpreted as a marker lesion for a severe trauma. A recent autopsy study [13] after fatal falls from height found sternal fractures to be present in 25 cases involving heart injuries (76%) with 16% of these with multiple sternal fractures, and in only 5 cases without heart injuries (18%). It was concluded that the presence of severe sternal fractures can be used as an indicator of possible cardiac trauma, which is supported by data of De WAELE et al. [14] as well as by our high overall mortality rate.

Concomitant injuries

The major concomitant injuries associated with sternal fractures in our study among 42.055 patients were bruises of soft tissue without any significant change over time within the 20 years of observation. The second frequent concomitant injury associated with sternal fractures were spine injuries in one-third of all cases, with cervical whiplash injuries dominating, followed by thoracic and lumbar spine fractures. Others reported a lower rate of whiplash injury (3%, ATHANASSIADI et al, 15.5%, von GARREL et al.) and fractures of the spine (4%, ATHANASSIADI et al., 13%, von GARREL et al.) with predominant thoracic spine fractures.

Concomitant spinal injuries are evident in case of sternal fractures with certain implications for the spinal stability. In a cadaver study [15] to determine the amount of stability the rib cage imparts to the thoracic spine and to show the amount of stability lost by a sternal fracture it was recently found that the rib cage and sternum provide 40% of the stability of the thoracic spine in flexion-extension, 35% of the stability in lateral bending, and 31% in axial rotation. An indirect flexion-compression type of sternal fracture decreases the stability of the thoracic spine by 42% in flexion/extension, 22% in lateral bending, and 15% in axial rotation. A sternal fracture decreases therefore the stability of the thorax dramatically, thus a sternal fracture associated with a thoracic spine injury or a multiple rib fracture could be an unstable combination of injuries after accidents, as seen in a case of multiple thoracic spine wedge fractures and sternal fracture [16]. Multiple rib fractures have been reported in 10.5% by von GARREL, which have somehow the same occurrence rate than observed by us (1985-94 13.7%, 1995-2004 12.4%). Regarding the 11.2% of patients dying at the scene with a sternal fracture, 39.1% had fatal thoracic injuries, 13% fatal head injuries, 8.7% fatal abdominal injuries, 34.8% died because of a combination as polytraumtized. Among 99 patients with sternal fractures, no significant increase of aortic ruptures was reported by STURM et al. [17]. However, currently no data regarding these preclinical dead patients have been reported after car crashes yet.

Treatment

Sternal fractures are most often treated conservatively with reasonable results regarding complete bony union and pain control [18]. Surgery is indicated in case of severe displacement, impairment due to severe pain limiting ventilation or in case of non-union of the sternum due to a pseudarthrosis sterni [19], often in a delayed fashion. Different operative techniques have been reported only in small series yet, such as circumferential wiring as in cardiac surgery or plates [20]. Based on our results one cannot derive a straight and strong recommendation for a surgical approach to stabilize any sternal fracture occurring in traffic accidents. However, given the significant loss of thoracic spine stability after a sternal fracture, which itself is often associated with spinal injuries in one-third of the cases, the restoration of the thoracic cage supports the goal of sternal and spinal repair. Future outcome studies should focus on this issue in more detail.

Limitations

Certain limitations have to be mentioned. The data collection was done by special trained personnel of the Accident Research Unit. Nevertheless, the data collected by the specialized personnel might be influenced by the fact that patients were transported and treated by different physicians in various hospitals in the Hannover region. It has been shown that diagnosis can be made best with computertomography and ultrasound rather that conventional x-ray, but we cannot exclude from our data that patients might be undiagnosed regarding a sternal fracture. Furthermore, the important question of preclinical rescue time in case of polytraumatized patients might affect outcome, which has to be taken into account regarding the mortality rate. Based on the fact that the patients were transferred in different hospitals, the indications for sternal and/or spinal surgery might vary to some degree. However, this study among a patient group of 42,055 patients over a 20-year period adds information regarding the effect of evolutional aspects of the vehicles as well as the distribution of concomitant injuries.

Conclusion

Sternal fractures occur most often in old cars to seat-belted drivers in frontal crashes. Severe multiple rib fractures and lung contusion are concomitant injuries each in more than 10% indicating the severity of the car crash. Concomitant spinal injuries, occurring in one-third of all cases, may deteriorate thoracic stability significantly with further emphasis on a thorough clinical examination in case of a sternal fracture.

References

[1] E. ARAJÄRVI, S. SANTAVIRTA: Chest injuries sustained in severe traffic accidents by seat-belt wearers. J Trauma 1989;29:37-41

[2] M. MAHLFELD, J. FRANKE, K. MAHLFELD: Ultrasound diagnosis of sternum fractures. Zentralbl Chir 2001;126(1):62-4

[3] J. ALKADHI, S. WILDERMUTH, B. MARINCEK, T. BOEHM: Accuracy and time efficiency for the detection of thoracic cage fractures: volume rendering compared with transverse computed tomography images. J Comput Assist Tomogr 2004;28(3):378-85

[4] G.T. LOO, J.H. SIEGEL, P.C. DISCHINGER, D. RIXEN, A.R. BURGESS, M.D. ADDIS, T. O'QUINN, L. McCAMMON, C.B. SCHMIDHAUSER, P. MARSH, P.A. HODGE, F. BENTS: Airbag protection versus compartment intrusion effect determines the pattern of injuries in multiple trauma motor vehicle crashes. J Trauma 1996;41:935-51

[5] M. RICHTER, C. KRETTEK, D. OTTE, B. WIESE, M. STALP, S. ERNST, H.C. PAPE: Correlation between crash severity, injury severity, and clinical course in car occupants with thoracic trauma: a technical and medical study. J Trauma 2001;50:10-6

[6] T. von GARREL, A. INCE, A. JUNGE, M. SCHNABEL, C. BAHRS: The sternal fracture: radiographic analysis of 200 fractures with special reference to concomitant injuries. J Trauma 2004;57:837-44

[7] K. ATHANASSIADI, M. GERAZOUNIS, M. MOUSTARDAS, E. MATAXAS: Sternal fractures: retrospective analysis of 100 cases. World J Surg 2002;26:1243-6

[8] A.W. FOWLER: Flexion/compression injury of the sternum. J Bone Joint Surg 1957;39B: 487-97

[9] M.W. HILLS, A.M. DELPRADO, S.A. DEANE: Sternal fractures: associated injuries and management. J Trauma 1993;35:55-60

[10] J.G. BROOKES, R.J. DUNN, I.R. ROGERS: Sternal fractures: a retrospective analysis of 272 cases. J Trauma 1993;35:46-54

[11] H.K. JONES, G.G. McBRIDE, R.C. MUMBY: Sternal fractures associated with spinal injury. J Trauma 1989;29:360-4

[12] M. RICHTER, H. THERMANN, B. WIPPERMANN, D. OTTE, H.E. SCHRATT, H. TSCHERNE: Foot fractures in restrained front seat car occupants: a long term study over twenty-three years. J Orthop Trauma 2001;15:287-93

[13] E.E. TURK, M. TSOKOS: Blunt cardiac trauma caused by fatal falls from height: An autopsy-based assessment of the injury pattern. J Trauma 2004;57:301-4

[14] J.J. de WAELE, P.A.A. CALLE, L. BLONDEEL, F.E.G. VERMASSEN: Blunt cardiac injury in patients with isolated sternal fractures: the importance of fracture grading. Eur J Trauma 2002;3:178-82

[15] R. WATKINS IV, R. WATKINS III, L. WILLIAMS, S. AHLBRAND, R. GARCIA, A. KARAMANIAN, L. SHARP, C. VO, T. HEDMANN: Stability provided by the sternum and rib cage in the thoracic spine. Spine 2005;30(11):1283-6

[16] J.M. LUND, A .CHOJNOWSKI, R. CRAWFORD: Multiple thoracic spine wedge fractures with associated sternal fracture: an unstable combination. Injury 2001;32:254-5

[17] J.T. STURM, M.G. LUXENBERG, B.M .MOUDRY, J.F. PERRY Jr.: Does sternal fracture increase the risk for aortic rupture? Ann Thorac Surg 1989;48:697-8

[18] J. BROOKES, R. DUNN, I. ROGERS: Sternal fractures: a retrospective analysis of 272 cases. J Trauma 1993;35:46-52

[19] S. HENDRICKSON, K. KOGER, C. MORCA, R. APONTE, P. SMITH, L. LEVIN: Sternal plating for the treatment of sternal non-union. Ann Thorac Surg 1996;62:512-18

[20] W. OZAKI, S. BUCHMAN, M. IANNETTONI, E. FRANKENBURG: Biomechanical study of sternal closure using rigid fixation techniques in human cadavers. Ann Thorac Surg 1998;65:1600-5

S. Rohrer, L. Hannawald
Accident Research Unit, University of Technology (TU) Dresden, Germany

R. Koch
TU Dresden, Medical Faculty, Department of Informatics and Biometry, Dresden, Germany

H. Zwipp
TU Dresden, Medical Faculty, Department of Accident and Reconstructive Surgery, Dresden, Germany

Mortality of Occupants in Real Crash Scenarios – A Multivariate Analysis of Influences Regarding Mortality

Abstract

While the number of fatal accidents is diminishing every year, there is still a need of improvement and action to prevent these deaths. Basis for this purpose has to be an analysis about the factors influencing the car crash mortality. There are various studies describing the univariate influence of several factors, but crash scenarios are too complex to be described by a single variable. The multivariate analysis respects the interference of the variables and gets so to more detailed and representative results.

This multivariate analysis is based on about 2,600 cases (the data have been collected by the accident research units Hannover and Dresden (during the years 1999-2003). This paper presents a multivariate model (containing ten different variables) which detects 93% of these cases properly. This means it detects the cases as truly survived and truly death.

Notation

AUC	Area under the curve
CI	Confidence Interval
EES	Energy Equivalent Speed
MAIS	Maximal Abbreviated Injury Scale Value
OR	Odds Ratio
PROCAM	Prospective Cardiovascular Münster Study
ROC	Receiver Operating Characteristic

Introduction

There is no discussion about the necessity of traffic for our society. But there is also absolutely no doubt about the dangers which lies herein. Thanks to various improvements in different fields, especially in traffic safety (car design, road construction) we achieved an enormous decline in traffic death and injury severity. Major campaigns to increase safety belt use and to reduce impaired driving and the efforts of legislation were major contributors to the reduction in fatalities and in the fatality rate.

The highest number of fatal accidents in Germany was seen in 1970; more than 21,000 people lost their lives (see Figure 1). The German government took action and passed a law which obliged the automobile industry to install seat-belts in cars. This law was followed by the compulsion for passengers to use this restraint system (1976). Other major points, responsible for this steady decline, were the improvements in the emergency treatment at the scene of the accident and perhaps more important, the implementation of an emergency call system and the realization of an emergency telephone system along the road (1971, invented by Björn STEIGER). Till then it was absolutely normal to wait up to an hour before the ambulance car arrived. Also in the year 1970 the first rescue helicopter started his work. New findings concerning the pathophysiology of the shock and new imaging methods in the emergency room, e.g. the 16 scan computer tomography, led to a reduction of mortality. Nowadays the number of traffic deaths is as low as never before, although the quantity of

Figure 1: Fatalities in Germany from 1953 until 2004 (until 1989 numbers refer to Federal Republic of Germany and German Democratic Republic, since 1990 numbers represent the reunited Germany) [1, 2]

cars is three times higher than in 1970. So today the drivers on our roads are safer than they have ever been, in part because of the safer cars, higher safety belt use and stronger safety laws.

Despite these improvements, there are about 40,000 fatalities every year in Europe, which corresponds to the population of a town. Considering the age of these victims this number is dramatic, because most of them are young with full capacity for work. Concerning the economical feature of car crashes the direct costs amount to 45 billion Euro per year; the indirect costs are three to four times higher. Analogously to this Figure the annual amount of 160 billion Euros is assessed, this sum corresponds to 2% of the gross national product of the European Union [3].

But as long as the number of fatalities remains as high as it is, the efforts to reduce the mortality have to be continued. Therefore it is still of enormous importance to determine the factors associated with a higher risk of mortality. The analysis of data pools of traffic accident research institutions can detect negative trends. Only by this procedure it is possible to take early countermeasures.

Numerous studies described the univariate influence of different variables (such as seat-belt use, gender, age,…) on the mortality. But crash scenarios are too complex to be described by only one variable. The univariat analysis also often neglects the existence of confounders or covariates. With a multivariate analysis it is possible to examine the influence of several factors on the same outcome (mortality). Further, the multivariate analysis respects the interference between the different influencing factors and gets so to more detailed and more representative results. The odds ratio of the multivariate analysis reflects a more realistic probability.

Material and methods

Accident team structure, equipment and dataset

In Hannover (since 1973) and Dresden (since 1999) local traffic accident research units exist. They collect, code and report prospective data on motor vehicle crashes with at least one injured person. The team consists of two technicians, one medical student and one coordinator who stays at place to answer the phone and to guide the team quickly to the scene of the accident. The team is provided with two emergency vehicles and after being notified by police dispatchers they arrive often simultaneously with the rescue personnel on scene. In the field they record among other things the following data:

- Number, type and construction year of involved automobiles.
- Photographs for measurement of distance and deformations.
- Energy Equivalent Speed (EES), v, collision speed.
- Traffic control, road condition, weather condition.
- Reason for the accident.
- Deformities of the vehicle.
- Number of involved persons, number of injured persons.
- Personal data of the involved drivers or passengers (date of birth, height, weight,…).
- Transport of the injured.
- Initial assessment of injury type and severity [X-ray, ISS, AIS, incidence of multiple injury (polytrauma)].
- Treatment in the hospital.

All the collected information is supplied to a special data pool called GIDAS (German In-Depth Accident Study). To achieve representative results, it is necessary to record as many accidents as possible. But with the increasing quantity of recorded car crashes the quality of registered variables diminishes. The GIDAS data pool contains a healthy combination of 2,000 reported accidents per year with more than 2,000 single variables to code for each accident.

Definition of some important statistical terms

Each statistical test has an associated null hypothesis, the p-value is the probability that the sample could have been drawn from the population being tested (or fictive samples which are still more different from the null hypothesis), given the assumption that the null hypothesis is true. Null hypotheses are typically statements of no difference or effect. A p-value close to zero signals that the null hypothesis is false and that a difference is very likely to exist. Large p-values closer to 1.0 imply that there is no detectable difference for the sample size used.

Odds is the ratio of the probability something is true divided by the probability that it is not. An odds ratio is the ratio of two odds.

$$OR = \frac{\text{Odd for death by exposure}}{\text{Odd for death by non-exposure}} \qquad (1)$$

An odds ratio of 1.0 means, the independent (here exposure) has no effect on the dependent (here death). The larger the difference between the observed odds ratio and 1.0, the stronger the relationship. An odds ratio below 1.0 indicates that the independent is associated with a decrease in the odds. An odds ratio above 1.0 indicates an increase, thus the independent leads to an increase in odds and risk. Odds ratios are to be understood like relative risks. Multivariately, they can be estimated by logistic regression models.

If the 95% confidence interval on the odds ratio includes the value 1.0, the variable is not considered as a useful predictor variable. Thus, the independent variable is not associated with a change in the odds.

Cross-validation can be used to estimate the generalization error of the model. It is one approach estimating how well the model of the training data is going to perform on future as-yet-unseen data. Leave-one-out cross validation means that the function approximator is trained on all the data except for one point and that a prediction is made for that point. The average error is computed and used to evaluate the model.

An ROC curve is a graphical representation of the trade between sensitivity and specifity for every possible cut off of the estimated probability for the considered event (here death) estimated by a logistic regression model. By tradition, the plot shows the false positive rate (1-specifity) on the x-axis and the sensitivity on the y-axis. A ROC curve is good when it climbs rapidly towards upper left hand corner of the graph. This means that the sensitivity is high and the false positive rate is low. When the ROC curve follows a diagonal path from the lower left hand corner to the upper right hand corner it means that this test is no better than flipping a coin. Cause every improvement in false positive rate is matched by a corresponding decline in sensitivity. Quantifying how quickly the ROC curve rises is possible by measuring the area under the curve (AUC). The larger the area the better the prognosis. If the area is 1.0 the test is ideal; if the area is 0.5 then the probability for right prognosis is not more than chance.

So the closer the area is to 1.0, the better the test is, and the closer the area is to 0.5 the worser the test is.

Statistical methods

When the dependent variable is a dichotomy (here is the considered event the accidental death: yes/no) and the independent variable is of any type, a logistic regression is used. The regression equation reads as follows [4, 5]:

Log it (considered event)=
$$b_0 + b_1X_1 + b_2X_2 + \ldots + b_jX_j \qquad (2)$$

with the definition of logit:

log it (event)=log [odds(event)]=

$$\log \frac{\text{probability(event)}}{1 - \text{probability(event}} \qquad (3)$$

For the multiple regression it is necessary to determine the parameters b_0, b_1, b_2,..., b_J so that the likelihood of the sample is maximal.

The estimation of parameters and the validation of the resulting regression model are an object of statistical software, e.g. SAS® or SPSS®.

We included cases of the years 1999-2003, but only accidents with car drivers or passengers who sustained an injury. Condition for consideration was further the existence of the EES and the MAIS; if theses two variables were missing or coded "unknown" the case was excluded.

The multivariate analysis requires complete cases; the missing of the value of one variable leads to an exclusion of the whole case. Therefore this form of analysis demands a very high number of cases. The univariate analysis was carried out with 3,418 cases (with 77 fatalities), for the multivariate analysis this number was reduced to 2,609 cases (with 50 fatalities). Univariate estimates of the odds ratio with a 95% Confidence Interval (CI) were the starting point to find multivariate predictors. The development of different models to predict the mortality was carried out with manual and automatic steps. We used the so called forward stepwise method in which the likelihood ratio test determines which variables are added to the model. Starting with the constant, one variable is added after another in the order they predict the mortality as the best. Criteria for the comparison of different models were adequate validity (tested with the Hosmer-Lemeshow goodness of fit test, ROC- and AUC-analysis, Wald test of the coefficients), good interpretation and numeric stability (SPSS-results tested in SAS). After cross-validation the final model detects 92,62% of the cases in the right manner, which means it declares properly death or survival (see Figure 2).

Proceeding a univariate as well as a multivariate analysis several combinations are possible (see Table 1).

In conclusion:

- Univariate assessments can be falsified by bias; this effect can be uncovered by multivariate models.

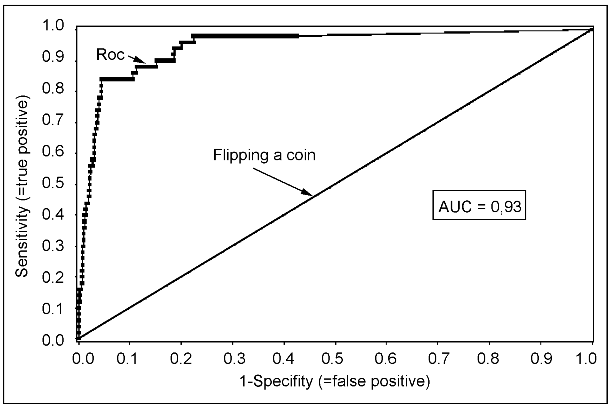


Figure 2: The ROC curve and the AUC of the multivariate analysis. The area under the curve represents the cases which are properly detected by this model

Univariate	Multivariate	Conclusion
significant	significant	Confirmation of the significance of the covariate
not significant	dispensable	Confirmation of the nonsignificance of the covariate
significant	dispensable	Multivariate analysis leads to devaluation. Reason either: a) Univariate pretended significance or b) The diagnostic/prognostic information of the covariate is already described by another covariate which is also contained in the model (e.g. interference/correlation of the covariates)
not significant	significant	Multivariate analysis leads to revaluation. Reason is an univariate covered significance (e.g. mixed population with opposite correlation in the different groups of the population)

Table 1: Comparison of the uni- and multivariate assessment [6]

- The assessment of the diagnostic/ prognostic significance of potential covariates can never finally answer the question of causal connection.
- Even with the same data pool it is possible to create different optimal models, which are equivalent in their quality. This means that the multivariate assessment of the covariates can differ. This is no contradiction, because the models have only a describing character for the relation with the objective variable (here: mortality).

Results

The univariate analysis considers only the influence of one variable on the mortality. The following table (Table 2) contains 25 different variables, whose influence is analysed independently from the others, and which are the basis for the multivariate choice of the optimal logistic regression model.

The resulting optimal multivariate model (see Table 3) contains ten different variables, all these variables are included simultaneously into the analysis. It is objective to determine the influence of the independent variable X (for example gender) on the dependent variable Y (here: death) in consideration of the fact that a third variable Z (for example EES) also affects Y.

The majority of the variables which are univariately significant shows also significant results in the multivariate analysis (see Table 4). The variable “passenger” shows uni- and multivariately no significance, therefore this variable can be neglected in further analysis. The variable “gender”, which demonstrates in the univariate analysis an increased mortality risk for the males (OR=1,78) is devaluated in the multivariate model. By contrast, the characteristic older than 60 years shows a significantly increased mortality risk in the multivariate analysis. Therefore the variable “age” is revaluated.

It is important to detect which of the variables have confounders. These variables which show univariately higher or lower values of OR, as in the multivariate analysis must have covariates (see Table 5). Because the interactions between the different variables are detected and corrected in the multivariate analysis, therefore this OR is more realistic and closer to reality.

	n	Regression coefficient	s.e.	p-value	OR	95% CI
Energy Equivalent Speed (EES) in kph	3418					
0 –15 (ref.)	1036					
16 – 30	1459	1,742	1,061	0,101	5,71	0,71...45,69
31 – 45	624	3,168	1,036	0,002**	23,80	3,12...181,09
46 – 60	216	4,765	1,025	0,000***	117,37	15,73...875,87
>60	83	6,476	1,026	0,000***	649,41	87,00...4847,30
Gender	3347					
female (ref.)	1582					
male	1765	0,577	0,244	0,018*	1,78	1,11...2,87
Age in years	3323					
26-60 (ref.)	1702					
children up to 17	279	0,341	0,391	0,473	1,41	0,65...3,06
18-25	1027	0,042	0,879	0,766	1,04	0,61...1,79
>60	315	0,446	0,221	0,249	1,56	0,77...3,19
BMI °	2734					
normal (ref.)	1555					
overweight	774	0,367	0,341	0,282	1,44	0,74...2,82
obese	273	0,496	0,468	0,289	1,64	0,66...4,11
underweight	132	0,117	0,746	0,876	1,12	0,26...4,85
Age of driving license	1877					
>3 years (ref.)	1373					
≤3 years	504	0,139	0,425	0,743	1,15	0,50...2,64
Accident location	1763					
known (ref.)	1234					
unknown	529	-0,334	0,574	0,560	0,72	0,23...2,21
Blood alcohol concentration^	3282					
<0,03mg/l (ref.)	3226					
≥0,03mg/l	56	1,643	0,486	0,001***	5,17	1,99...13,42
Use of seeing aid	3032					
no (ref.)	2295					
yes	737	-1,900	0,725	0,009**	0,15	0,04...0,62
Swerve to avoid hitting	1582					
no (ref.)	872					
yes	710	-0,064	0,372	0,863	0,94	0,45..1,95
Braking	1618					
yes (ref.)	859					
no	759	1,036	0,399	0,009**	2,82	1,29...6,16
Illness	3158					
no (ref.)	2849					
at least one	309	0,414	0,412	0,315	1,51	0,67...3,39
Medicaments	3210					
no (ref.)	2917					
at least one	293	-1,779	1,010	0,078	0,17	0,02...1,22
Passenger	3418					
no (ref.)	2788					
at least one	630	-0,545	0,357	0,127	0,58	0,28...1,17
Belt usage	2925					
yes (ref.)	2682					
no	243	1,091	0,331	0,001***	2,98	1,56...5,70
Front airbag	3124					
yes (ref.)	1151					
no	1973	0,032	0,248	0,896	1,03	0,64...1,68
Airbag deployment	1151					
yes (ref.)	539					
no	612	-1,867	0,547	0,001***	0,16	0,05...0,45
Site	3418					
urban (ref.)	1898					
rural	1520	1,949	0,316	0,000***	7,02	3,78...13,05
Light conditions	3414					
daylight (ref.)	2130					
darkness, dawn	1284	0,705	0,232	0,002**	2,02	1,29...3,19
Locality of accident	3277					
within built up area (ref.)	2126					
outside built up area	1151	0,711	0,234	0,002**	2,04	1,29... 3,22

Table 2: Univariate analysis

	n	Regression coefficient	s.e.	p-value	OR	95% CI
Scene of the accident	3404					
junction/crossroad (ref.)	1470					
curve	604	2,435	0,454	0,000***	11,42	4,69...27,80
straight line	1330	2,122	0,437	0,000***	8,35	3,55...19,65
Rainfall	3392					
no (ref.)	2559					
yes	833	-0,221	0,284	0,437	0,80	0,46...1,40
Condition of the road	3404					
good (ref.)	3243					
affected	161	-0,40	1,014	0,694	0,67	0,09...4,90
Surface of the road	3400					
dry (ref.)	2115					
wet, frozen, snow covered	1285	-0,179	0,244	0,461	0,84	0,52...1,35
Power of the car in kW	2843					
<50 (ref.)	853					
50-69	1077	0,308	0,309	0,319	1,36	0,74...2,49
70-89	528	0,045	0,391	0,908	1,05	0,49...2,25
>90	385	-0,250	0,479	0,601	0,78	0,31...1,99
Seating position	3418					
front passenger (ref.)	2984					
rear seat passenger	437	-0,096	0,358	0,788	0,91	0,45...1,83

° BMI is adjusted to age and gender of the children (according to the definitions of the WHO)
^ The blood alcohol concentration is only ascertained for drivers and only for the autopsied dead
* (p≤0,05), ** (p≤0,01), *** (p≤0,001)

Table 2: Continuation

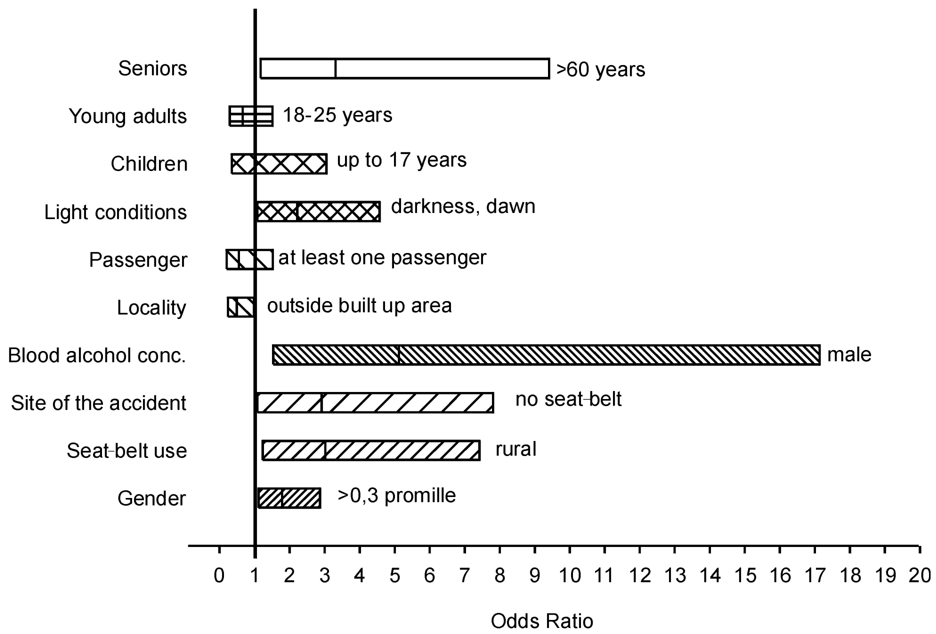


Figure 3: The different variables of the multivariate analysis with an increase (OR >1) or a decrease in mortality risk (OR <1). Significant results do not include 1.0

The variables “belt usage”, “light conditions”, “passenger” and “blood alcohol concentration” show uni- and multivariately the same OR. The variable “locality of the accident” demonstrates univariate an increased mortality risk (OR=2,04) for the characteristic “outside built up area”. In the multivariately model there is seen an inverse effect: “outside built up area” seems to have a protective effect (OR=0,49) on the mortality risk. The variables “site”, “EES”, “scene of the accident” and “gender” have univariately a higher OR as multivariately and the variable “age” has univariately a lower OR than in the multivariate model, therefore they have confounders.

	n	Regression coefficient	s.e.	p-value	OR	95% CI
Constant factor		-8.7761				
Belt usage						
yes (ref.)	2399					
no	210	1,1045	0,4594	0,0162*	3,02	1,23 ... 7,42
Site						
urban (ref.)	1450					
rural	1159	1,0671	0,5043	0,0343*	2,91	1,08 ... 7,81
Blood alcohol concentration^						
<0,03mg/l (ref.)	2567					
≥0,03mg/l	42	1,6326	0,6168	0,0081**	5,12	1,53 … 17,14
Energy equivalent speed(EES)						
0 –15kph (ref.)	794					
16 – 30kph	1119	0,7868	1,1285	0,4857	2,20	0,24 ... 20,06
31 – 45kph	478	2,2277	1,0657	0,0366*	9,28	1,15 ... 74,93
46 – 60kph	156	3,4933	1,0675	0,0011**	32,90	4,06 ... 266,58
>60kph	62	5,5121	1,0724	<,0001***	247,67	30,27...>999,9
Light conditions						
daylight(ref.)	1640					
darkness, dawn	969	0,7993	0,3673	0,0295*	2,22	1,08 ... 4,57
Locality of accident						
within built up area (ref.)	1657					
outside built up area	952	-0,7214	0,3582	0,0440*	0,49	0,24 ... 0,98
Gender						
female (ref.)	1279					
male	1330	0,1426	0,3660	0,6969	1,15	0,56 ... 2,36
Age						
26-60 years (ref.)	1356					
children up to 17 years	219	0,0305	0,5528	0,9560	1,03	0,35 ... 3,05
18-25 years >	779	-0,4124	0,4217	0,3281	0,66	0,29 ... 1,51
60 years	255	1,1977	0,5329	0,0246*	3,31	1,17 ... 9,41
Passenger						
no (ref.)	2127					
at least one	482	-0,6044	0,5206	0,2456	0,55	0,20 ...1,52
Scene of the accident						
junction/crossroad (ref.)	1147					
curve	467	2,0285	0,7953	0,0108*	7,60	1,60 ... 36,13
straight line	995	1,6204	0,7886	0,0399*	5,05	1,08 ... 23,71

^ The blood alcohol concentration is only ascertained for drivers and only for the autopsied dead
* (p≤0,05), ** (p≤0,01), *** (p≤0,001)

Table 3: Multivariate analysis

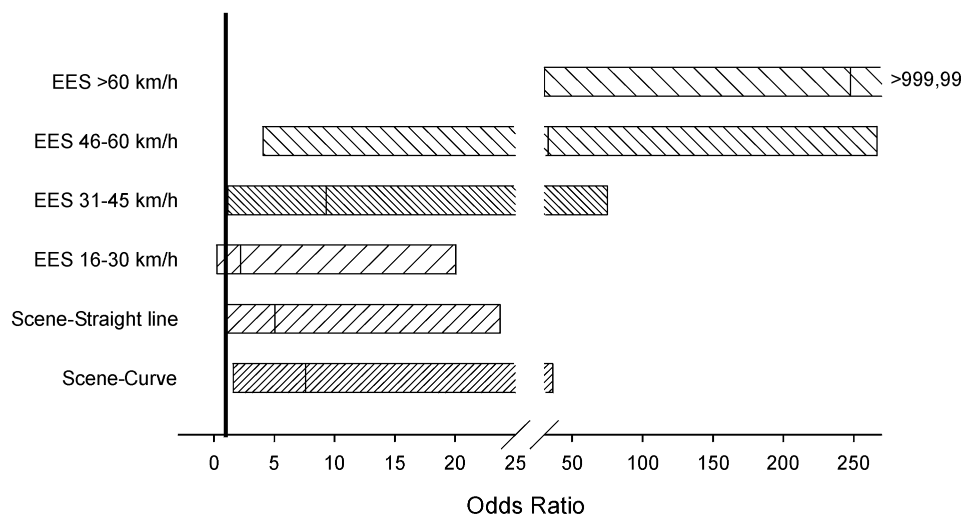


Figure 4: The different variables of the multivariate analysis with an increase in mortality risk (OR >1) or a decrease in mortality risk (OR <1). Significant results do not include 1.0. Break between 25 and 30

Univariate	Multivariate	Variables
significant	significant	• Belt usage • Site • Blood alcohol concentration • EES (31-45 kph, 46-60kph and >60kph) • Light conditions • Locality of the accident • Scene of the accident
not significant	dispensable	• Passenger
significant	dispensable	• Gender
not significant	significant	• Age (>60 years)

Table 4: Overview of the results of the uni- and multivariate analysis concerning the significance

Univariate higher OR as multivariate	• Site • EES • Scene of the accident • Gender
Univariate lower OR as multivariate	• Age
Uni- and multivariate same OR	• Belt usage • Light conditions • Passenger • Blood alcohol concentration
Opposite effect in uni- and multivariate analysis	• Locality of the accident

Table 5: Overview of the different OR of the uni- and multivariate analysis (by variables with several characteristics, it was referred to the significant results)

Discussion

Which confounders these are can never finally be answered.

Site: By calculation of the OR of the variable “site” the multivariate model takes all the other nine variables also into consideration and respects the interference of the variables among themselves. One potential covariate is the EES. In rural areas higher driven speeds are possible which in the case of an accident ends in higher EES. The multivariate OR is therefore lower than the univariate, because the variable “site” is included in the variable “EES”. It is not possible to look only at the site; the driven speeds have also to be considered.

Scene: The scene of the accident depends mostly on the site and the locality. In rural or outside built up areas more curves and straight lines are existing than in urban areas where junctions and crossroads predominate. Therefore the scene has to be seen in context with the other variables.

	EES in kph					Total
	0-15	16-30	31-45	46-60	>60	
female	562	676	245	74	25	1582
male	454	756	365	134	56	1765
Total	1016	1432	610	208	81	3347

Table 6: Overview of the different EES-values in dependence on the gender

Gender: The significant OR for the males in the univariate analysis will not last the multivariate model. One explanation is the observation that males drive with higher speed (see Table 6) and their cars show higher EES after a crash. The information of the variable “gender” is also incorporated in the variable “EES”.

Age: In the univariate analysis the characteristic “older than 60 years” shows no significance. The multivariate model results in a three times higher mortality risk than the reference group with persons aged 26 to 60 years. This characteristic was revaluated. But it is not easly to answer which covariates these are.

EES: As seen above this variable affects others, but it is also influenced by others. The EES is probably dependent on the site, the locality, the gender, the light conditions and the scene of the accident.

Locality: This variable shows for “outside built up area” like forest, fields, meadow and so on, a two times higher risk. In the multivariate model a protective result (OR=0,5) is illustrated. This apparent contradiction is caused by the limited validity of the univariate model: considering solely the locality, it is true that outside built up areas more fatal accidents occur. The multivariate analysis demonstrates that rather the relation that roads outside built up areas are situated in the rural area and allow higher speed is decisive than the locality of the accident. Hence only in relation with the variables “site” and “EES” it is possible to interpret the variable “locality” properly.

Limits of the multivariate model

For each of the 50 deaths it is possible to determine the prediction quality/validity to know how precise the multivariate model predicted properly the death of this case. The analysis of cases which have not been predicted in a good manner can give detailed information about the limits of this multivariate model.

- Case number 1010825 (Figure 5) is not well predicted by this model (0,95%). Three variables show significant values (rural, straight line, night time driving) which are associated with a higher death risk. A car crashes on the highway into the rear of a truck with projected cargo. The front seat passenger dies. As the victim was a front seat passenger the blood alcohol concentration has not been determined. The seat-belt use is not so relevant as well, because the massive head injuries caused by the cargo cannot be prevented by a seat-belt. This example also shows that accidents with low EES-values (16-30kph) can lead to death, when the collision object is a massive object which penetrates into the interior and causes due to its height massive head injuries.
- Case number 1990343 (Figure 6) was not well identified (7,57%). After overtaking a truck, the car starts skidding and stops standing crosswise on the highway. The following truck crashes into the side of the car. Three variables show significance (straight line, darkness, EES 55kph). The dead person was the front seat passenger, so the blood alcohol was not determined.

The limits of this multivariate model are the detection of collisions with massive objects if the front seat passenger or other passengers lost their lives. The variable blood alcohol concentration is not suitable to determine the risk of the front seat passengers or the other occupants. Special accident scenarios, for example accidents due to projected cargo, are predicted insufficiently.

The Tables 2 and 3 contain the p-value, which serves as evaluation for the prediction validity. But how suitable are these variables to be accepted in the multivariate model? In which way do they express the death rate? The SPSS®-Program lists for each case and each variable the predicted probability.

The variable “site of the accident” for example distinguishes very well between survival or death

Figure 5: The truck with its cargo and the car

Figure 6: The arrow shows the direction of the truck

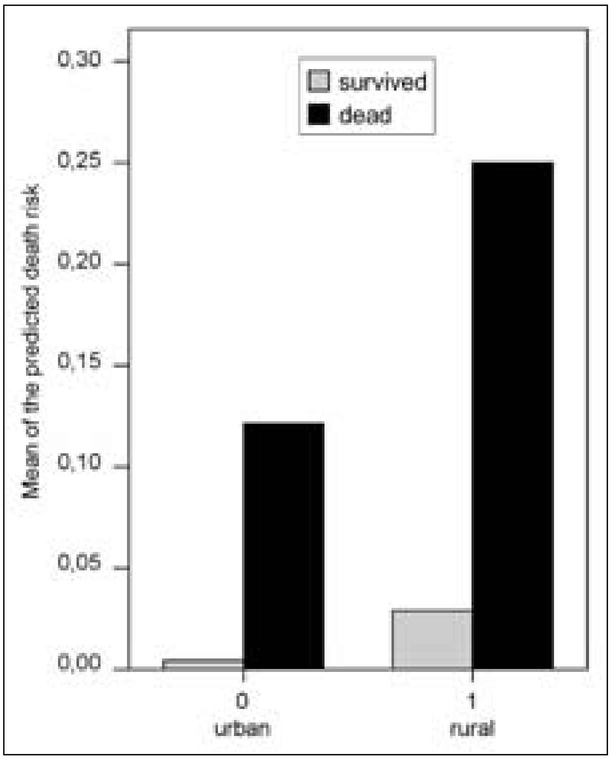


Figure 7: Mean of the predicted death risk for the variable “site of the accident”

(see Figure 7). By the characteristic value “rural” 25% of the cases with fatalities are properly

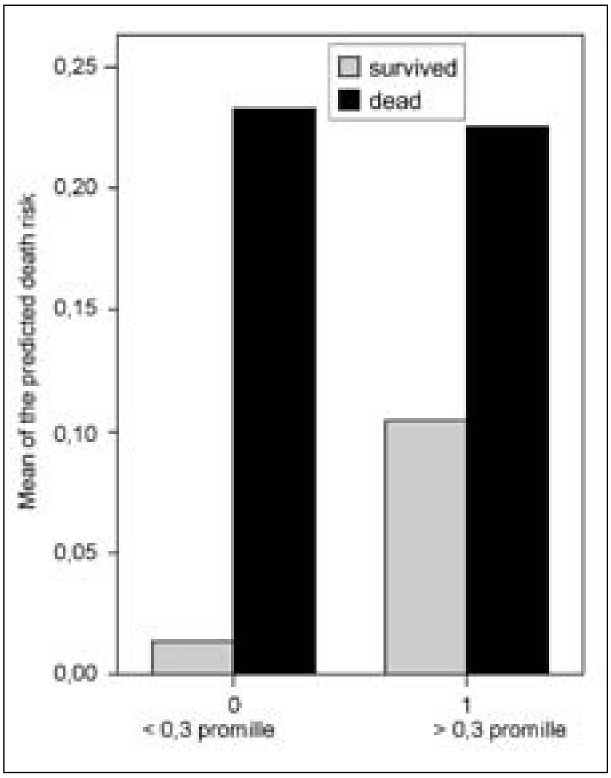


Figure 8: Mean of the predicted death risk for the variable "blood alcohol concentration"

detected as dead and about 12,5% by the characteristic "urban". The cases with the survivors show low mean predicted death rate. Therefore the variable "site of the accident" is very suited for this multivariat model.

The variable "blood alcohol concentration" is of less quality. Figure 8 shows that death is better predicted for those who have a blood alcohol concentration <0,03mg/l but the univariate analysis illustrates a 5 times higher risk for those who have a blood alcohol concentration >0,03mg/l. In the univariate analysis it is only considered if the difference between persons with <0,03 mg/l and persons with >0,03mg/l is significant. As seen in Table 7 the difference between 1,9% and 8,9% is significant. But this significance is favoured by the grouping: in the univariate analysis only 56 persons are in the group >0,03mg/l. Further this variable is not representative, because it does not consider the occupants. Usually the blood alcohol concentration is only considered for the drivers and if they are dead only for the autopsied persons.

For the graph (Figure 8) of the "mean of the predicted death risk" the predicted mortality is summarized. As more persons (60 victims) are dead with <0,03 mg/l, they are better predicted. Solely this variable is not suitable for predicting mortality, because there exists a lot of scenarios, where the driver or the occupants die without drinking any alcohol (e.g. after losing control, a truck crosses the halfway line and crashes into a oncoming car).

		survived	dead
Significant?	<0,03mg/l	3166 (98,1%)	60 (1,9%)
	>0,03mg/l	51 (91,1%)	5 (8,9%)

Table 7: Overview of the number (and percentage) of the survived and dead persons in dependence on the "blood alcohol concentration"

Just the entirety of all variables contained in the model determines the prediction validity of the model, which can be estimated by simple reclassification and cross validation. How precise a single variable serves to the prediction validity of the whole model, can only be answered by the p-value of all variables included to the model. By the combination of these variables are 93% of the cases detected as "truly survived" and "truly dead".

Conclusion

It was shown how critical it is to consider only the influence of one single variable on the mortality. Univariate analyses are simple to understand but their results are not realistic. The multivariate model allows more detailed results which are closer to reality. With this kind of analysis it is possible to consider several variables simultaneously and to respect their interferences. The multivariate analysis is based on a model which detects 93% of the cases properly. For the future it would be very interesting to develop a calculator for the car crash mortality based on a model which contains much more cases than considered here. Such a risk assessment calculator was developed to estimate the individual risk of a heart attack within the next 10 years based upon data of the PROCAM study [7]. The person has to give some information about gender, age, blood pressure, smoking of cigarettes and so on; the computer calculates than the risk to suffer a heart attack.

As a future vision the potential driver or occupant could answer some questions like:

- Light conditions during the drive (darkness, dawn vs. daylight).
- Seat-belt usage (yes vs. no).

- Existence of airbags (yes vs no).
- Age of the driver.
- Gender.
- Construction year of the vehicle.
- Predominating road type (highway vs roads in rural areas vs roads in urban areas).
- Estimated average speed.

Afterwards the calculator estimates the mortality risk if an accident happens. Especially for young drivers this calculator would be very interesting. By seeing the increased mortality risk for driving without a seat-belt or under the influence of alcohol they would perhaps drive more carefully and occupants would deny driving with an alcoholised driver.

References

[1] Bundesministerium für Verkehr- Bau und Wohnungswesen: Verkehr in Zahlen 2005/2006, Berlin, Deutscher Verkehrs-Verlag, page 180, 2005

[2] Ministerium des Inneren- Hauptabteilung Verkehrspolizei: Statistische Analyse des Verkehrsunfallgeschehens in der DDR, 1953-1989

[3] European Community: White Paper, European transport policy for 2010: time to decide, page 66, 2001

[4] R. KOCH: Schätzung von Risiken: Eine kurze Einführung in Ziele und Methoden, www.imib.med.tu-dresden.de/imib/biometrie/risikoschaetzungen.pdf

[5] L. KREIENBROCK, S. SCHACH: Epidemiologische Methoden, Jena, Gustav Fischer Verlag, 1995

[6] R. KOCH: Diagnostische bzw. prognostische Bedeutsamkeit einer Kovariablen-Vergleich uni- und multivariate Bewertung, www.imib.tu-dresden.de/imib/biometrie/Folien_logitmodelle_quer.pdf, 2003

[7] International Task Force for Prevention of Coronary Heart disease: PROCAM Risiko-Rechner, http://chdrisk.uni-muenster.de/calculator. php

Y. Watanabe
Institute for Traffic Accident Research and Data Analysis, Tokyo, Japan

Influence of Vehicle Properties on Neck Injuries in Rear-End Collisions

Abstract

Analyses were conducted to clarify the features of rear-end collisions, using an integrated accident database developed by the Institute for Traffic Accident Research and Data Analysis (ITARDA). Focusing on neck injuries in rear-end collisions, analyses were made of the relation to struck-vehicle properties. Regarding the relation to the initial year of registration, the results did not show that newer vehicles tended to have a lower no-neck-injury rate, which was defined in this study as an index. On the contrary, in some passenger car classes, it was observed that the no-neck-injury rate was higher in newer vehicles. The effect of an active head restraint system, which is one type of anti-whiplash device, was analyzed by using not only the no-neck-injury rate but also a regression analysis. The results showed that the effect of an active head restraint system on suppressing the incidence of neck injuries was statistically significant.

Introduction

In Japan, the number of traffic accident fatalities occurring within 24 hours totaled 11,451 in 1992. It has decreased consistently since then, falling to 7,358 in 2004 and to 6,871 in 2005. The number of fatalities occurring within 30 days has also steadily declined, dropping to 8,492 in 2004 and to 7,931 in 2005 as shown in Figure 1. This decrease is thought to result from various measures, including more extensive traffic safety education, road and vehicle improvements and better emergency medical care [1-3]. In contrast, the number of traffic accident injuries has been increasing for many years, totaling more than 1.1 million annually in recent years as shown in Figure 1, so further measures to reduce injuries are necessary.

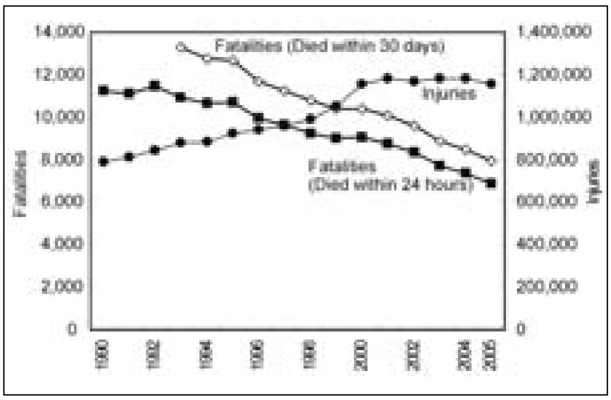


Figure 1: Trends in traffic accident fatalities and injuries

This study focused on rear-end collisions which account for many traffic accident injuries. The situation (as of 2004) for rear-end collisions in Japan and resultant neck injuries was analyzed using an integrated accident database developed by the Institute for Traffic Accident Research and Data Analysis (ITARDA). An investigation was made of whether neck injuries tend to occur in newer vehicles in the context of the increasing number of traffic accident injuries overall, and the effect of anti-whiplash devices, which have been spreading in recent years, was also examined using the integrated accident database.

Actual Situation for Rear-End Collisions and Injuries

Rear-end collisions

The trends in the number of traffic accidents by type are shown in Figure 2. Rear-end collisions show a marked upward trend and have consistently been the most numerous of all types of traffic accidents since 1996. In 2004, they accounted for approximately 31% of all traffic accidents. Figure 3 shows the trends in the number of casualties by type of accident. The number of casualties occurring in rear-end collisions has also tended to increase and accounted for approximately 35% of the total in 2004.

The number of rear-end collisions between vehicles was 279,098 in 2004. Limiting rear-end collisions to the combination that the striking vehicle is the primary party (culpable) and the struck vehicle is the secondary party (less culpable), the number of such combinations that year was 266,391. The combinations are broken down by vehicle type in Table 1. According to the table, the number of rear-end collisions in which the striking vehicle was an ordinary passenger car was 160,426, or approximately 60%. Of them, the number of cases in which the struck vehicle was a "passenger car or truck" and "ordinary or light" was 159,543, or approximately 99%. The number of rear-end collisions in which the struck vehicle was an ordinary passenger car was 166,350, or approximately 62%, and, of them, the number of cases in which the striking vehicle was a "passenger car or truck" and "ordinary or light" was 161,827, or approximately 97%. These Figures indicate that many of the striking and struck vehicles were ordinary passenger cars and that most of the other parties were passenger cars or trucks and were ordinary or light vehicles. Accordingly, the target vehicles for the subsequent analyses were limited to ordinary passenger cars whose other parties were passenger cars or trucks and were ordinary or light vehicles.

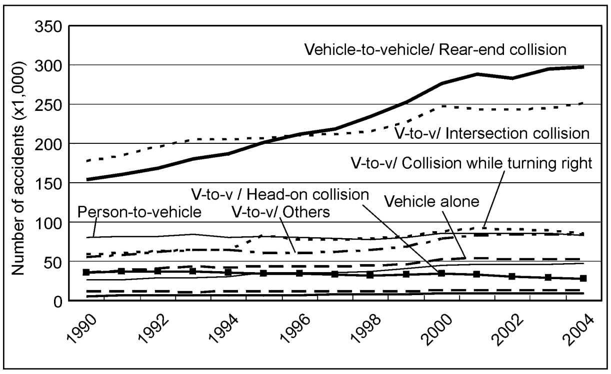


Figure 2: Trends in traffic accidents by type of accident

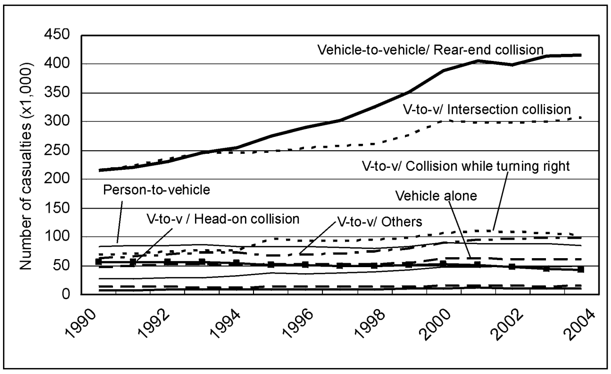


Figure 3: Trends in traffic accident casualties by type of accident

Injuries incurred by ordinary-passenger-car occupants in rear-end collisions

The injuries incurred by ordinary-passenger-car occupants in rear-end collisions in 2004 were analyzed in the striking and struck vehicles respectively under the following assumptions:

- Target vehicles for analysis: ordinary passenger cars.
- Other-party vehicle: passenger car or truck and ordinary or light vehicle.
- Striking vehicle: primary party (culpable).
- Struck vehicle: secondary party (less culpable) and struck in the entire rear-end area.
- Exclusion of multiple collisions.

The first analysis focused on the drivers. Figure 4 shows that approximately 99% of the 122,559 striking-vehicle drivers were not injured. In contrast, approximately 87% of the 126,618 struck-vehicle drivers were slightly injured, mainly in the neck, as shown in Figure 5. This suggests that attention should be paid to neck injuries in struck vehicles in rear-end collisions. On the other hand, approximately 73% of the 151,869 struck-vehicle occupants who mainly suffered neck injuries were

			Striking vehicle (primary party)								
			Passenger				Truck			Special vehicle	Total
			Bus, Minibus	Ordinary	Light	Mini-car	Large-sized special, Large-sized	Ordinary	Light	Special vehicle	Total
Struck vehicle (secondary party)	Passenger	Bus, Minibus	19	244	54	0	42	114	30	0	503
		Ordinary	444	104,340	25,357	2	4,028	21,502	10,628	49	166,350
		Light	98	32,323	11,288	2	1,062	5,868	4,227	25	54,893
		Mini-car	0	3	4	1	0	2	1	0	11
	Truck	Large-sized speczial, Large-sized	15	493	139	0	748	583	97	0	2,075
		Ordinary	76	10,641	2,352	1	1,324	4,818	1,350	12	20,574
	Special vehicle		1	143	38	0	13	40	25	1	261
	Total		694	160,429	43,031	6	7,758	36,113	18,266	97	266,391

Table 1: Number of rear-end collisions between vehicle by vehicle classification (2004)

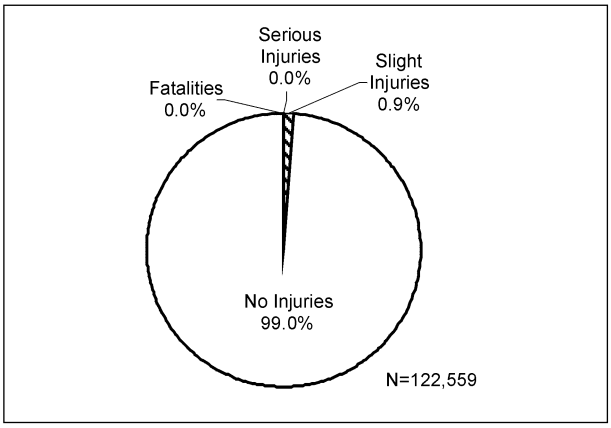


Figure 4: Injury severities of striking-vehicle drivers in rear-end collisions (ordinary passenger cars, primary parties, 2004)

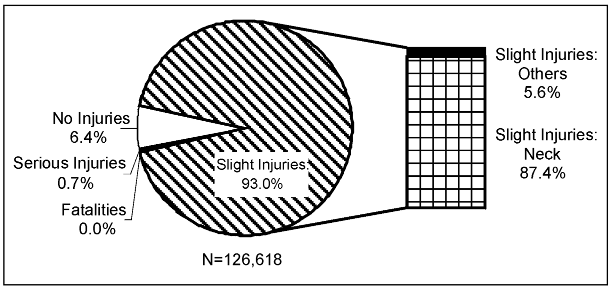


Figure 5: Injury severities of struck-vehicle drivers in rear-end collisions (ordinary passenger cars, secondary parties, 2004)

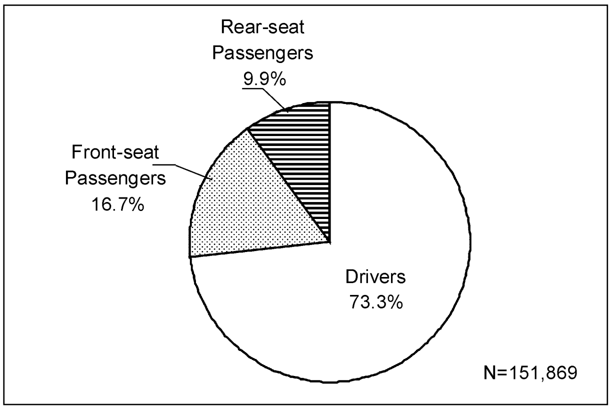


Figure 6: Seating positions of all occupants of struck vehicles in rear-end collisions (ordinary passenger cars, secondary parties, neck injured, 2004)

drivers, approximately 17% of them were front-seat passengers and approximately 10% of them were rear-seat passengers as shown in Figure 6. These figures indicate that struck-vehicle drivers have a high priority.

Neck injury incidence in rear-end collisions

Measures to prevent whiplash neck injuries in struck vehicles are desired. However, the mechanism of whiplash injuries is not fully understood at present, and there are differing opinions about the mechanism causing such injuries [4-8].

Definition of No-Neck-Injury Rate

An analysis was made of the relation of struck-vehicle properties to neck injuries in struck vehicles, which account for the greater portion of rear-end collision casualties. The index used in the analysis was the no-neck-injury rate defined as follows, based on the injury severity of struck-vehicle drivers:

No-neck-injury rate=

$$\frac{\text{No injuries x 100 (\%)}}{\text{Fatalities + Serious injuries + Slight injuries + No injuries}}$$

Casualties (fatalities, serious injuries and slight injuries) were restricted to those that mainly involved neck injuries. The types of serious and slight injuries were limited to sprains, dislocations or fractures in order to focus on injuries thought to be whiplash or an extension thereof. It will be noted that this index is used only for drivers because only drivers, as a rule, are counted among the no-injury vehicle occupants in ITARDA's integrated accident database.

The struck-vehicle properties analyzed in this study with this index were the initial year of registration and presence/absence of an anti-whiplash device.

Relation to Initial Year of Registration

Method and data

An investigation was made of whether neck injuries were apt to occur in newer struck vehicles, in view of the upward trend for casualties in rear-end collisions as shown in Figure 3. The relationship between the initial year of registration and the no-neck-injury rate of drivers in struck vehicles was analyzed using the integrated accident database. Each passenger car class was analyzed separately because the differing shapes and weights of different vehicle classes would affect the no-neck-injury rate. The definitions of the passenger car classes used by ITARDA are shown in Table 2. The analysis focused on rear-end collisions in 2004 that met the following conditions:

- Striking vehicle: passenger car or truck, ordinary or light, and primary party.
- Struck vehicle: secondary party and struck in the entire rear-end area.
- Exclusion of multiple collisions.

Results

The results in Figure 7 show that there was no tendency for the no-neck-injury rate of struck-vehicle drivers to decrease with a later initial year of registration of the struck vehicle. On the contrary, for the Sedan-B class (engine displacement of 1,500-2,000cc) and the Sedan-C class (engine displacement of over 2,000cc), the no-neck-injury rate tended to increase with a later initial year of registration of the struck vehicle.

Passenger car class
Family-Light
Sedan-A (engine displacement of under 1,500cc)
Sedan-B (engine displacement of 1,500-2,000cc)
Sedan-C (engine displacement of over 2,000cc)
Sports & Speciality
Wagon
1-Box & Minivan
SUV (Sport-utility vehicle)

Table 2: Definitions of passenger car classes

Effect of an Anti-Whiplash Device – Analyses 1

Method and data

To examine the effect of an anti-whiplash device, which has been spreading in recent years, vehicle models meeting the following requirements were selected, and the difference in the no-neck-injury rate between drivers of vehicles with and without such a device was analyzed:

- Ordinary passenger car with and without an anti-whiplash device (to exclude body influences such as the crash characteristics of the rear end).
- The device is not an option (to eliminate driver consciousness of whiplash).
- Presence of the device can be clearly distinguished according to the model (to calculate the no-neck-injury rate in the presence of the device).
- Vehicle models with and without the device were put on the market by 1999 (to secure a sufficient volume of accident data).

Only one vehicle meeting these requirements was found. This vehicle was Sedan-C put on the market in 1996. The anti-whiplash device fitted on this

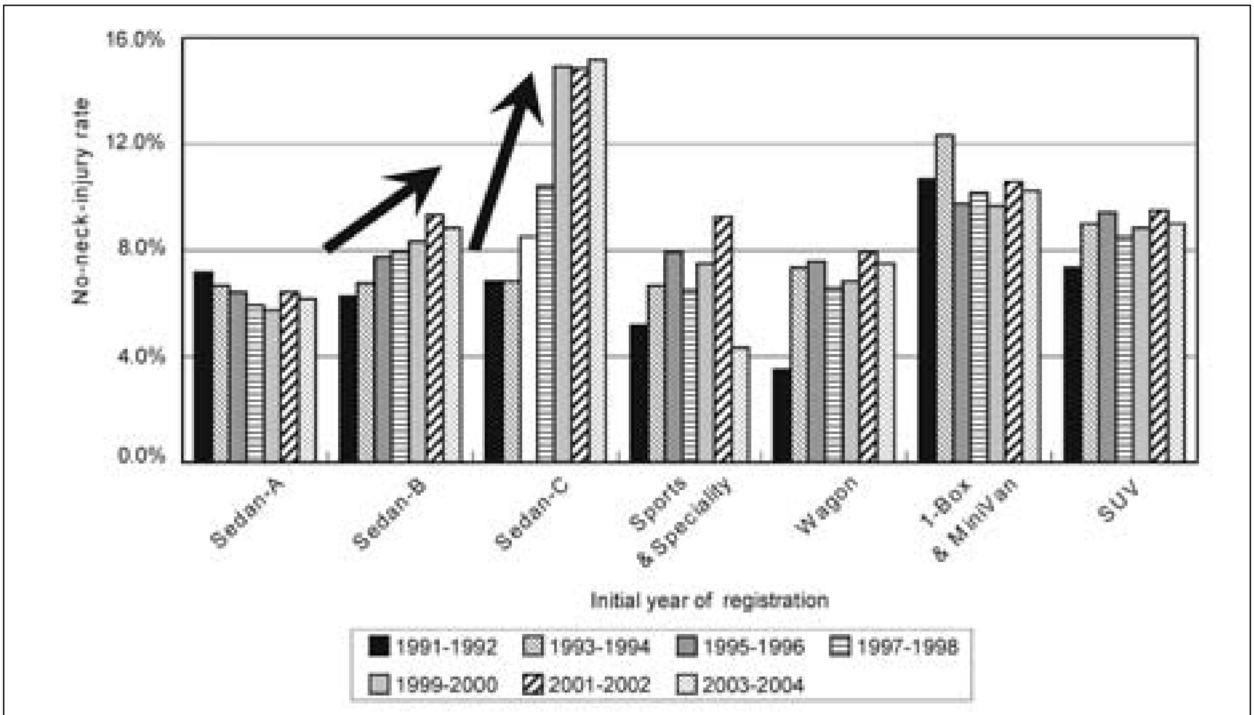


Figure 7 Relationship between no-neck-injury rate and initial year of registration of struck vehicles in rear-end collisions (ordinary passenger cars, secondary parties, 2004)

vehicle was an active head restraint (AHR) system [9]. An AHR system was not provided initially and became standard equipment on all models of this vehicle in the latter half of 1998.

The analysis focused on rear-end collisions occurring over five years from 2000 to 2004 and meeting the following conditions:

- Struck vehicle: the above-mentioned vehicle, struck in the entire rear-end area, and secondary party.
- Striking vehicle: passenger car or truck, ordinary or light, and primary party.
- Exclusion of multiple collisions.

Results

Under the conditions above, the numbers of drivers incurring mainly neck injuries or no injuries in this vehicle are shown in Table 3. Of 760 drivers, 105 suffered neck injuries with the AHR and 21 reported no injuries, whereas 587 incurred injuries without the AHR and 47 reported no injuries. The no-neck-injury rate with the AHR (16.7%) was higher than that without the AHR (7.4%) as shown in Table 3 and Figure 8.

	With AHR	w/o AHR
Fatal neck injuries	0	0
Serious neck injuries (sprains, dislocations, fractures)	1	4
Slight neck injuries (sprains, dislocations, fractures)	104	583
No injuries/Overall	21	47
Total	126	634
No-neck-injury rate	16.7%	7.4%
Z-statistic	3.324	
P-value	0.0009	

Table 3: Incidence of casualties and no injuries with/without AHR and results of statistical analysis

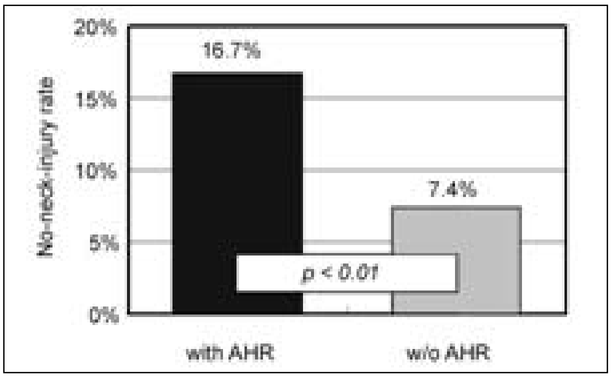


Figure 8: Influence of AHR on no-neck-injury rate

A two-sample test for equality of proportions was conducted between these no-neck-injury rates. The test statistic Z is given by:

$$Z = | p_1 - p_2 | / \sqrt{p(1 - p)(1/n_1 + 1/n_2)}$$

where,

$$p=(n_1p_1 + n_2p_2) / (n_1 + n_2)$$

According to these formulas, Z was 3.324, which means that the p-value in the two-sided test was 0.0009. These figures show that the no-neck-injury rate with the AHR was higher than that without the AHR at the 1% significance level.

Results of additional analysis following classification of factors

In the preceding discussion, it was statistically confirmed that the presence of an AHR influences the no-neck-injury rate. However, other factors that might influence the incidence of neck injuries in rear-end collisions, such as impact severity, gender and age, were not considered. For that reason, an investigation was made of whether there was a large difference in the composition of the factors in relation to the presence of an AHR. The results are shown in Figures 9 to 11. Pseudo-ΔV [10] is used

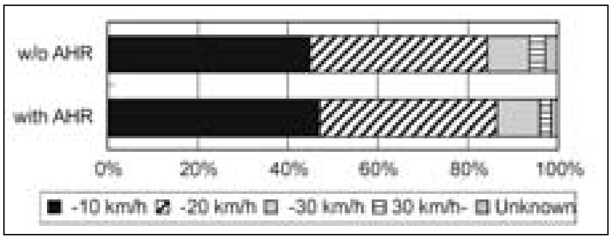


Figure 9: Distribution of pseudo-ΔV with/without AHR

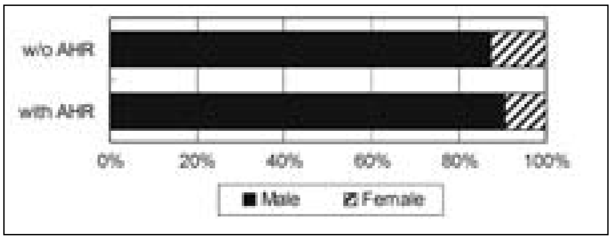


Figure 10: Distribution of gender with/without AHR

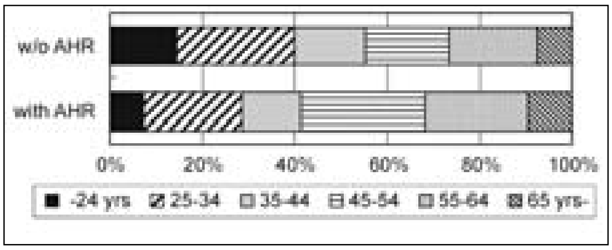


Figure 11: Distribution of age with/without AHR

as an index in Figure 9 to indicate the impact severity in a rear-end collision. Pseudo-ΔV of a struck vehicle can be calculated with the following equation, based on the struck-vehicle impact speed V_1, struck-vehicle weight M_1, striking-vehicle impact speed V_2 and striking-vehicle weight M_2 as shown in Figure 12.

$$\begin{aligned}\text{Pseudo-}\Delta V &= V - V_1\\ &= (M_1V_1 + M_2V_2) / (M_1 + M_2) - V_1\\ &= (V_2 - V_1)\, M_2 / (M_1 + M_2)\end{aligned}$$

Here, V means the speed of both vehicles after a rear-end collision and is assumed as follows:

- The impact speed is equal to the speed reported by the driver.
- The coefficient of rebound is 0 (e=0).

The results in Figures 9 to 11 indicate that there was no large difference in the composition of these factors due to the presence of an AHR, so it can be concluded that the factors did not influence the no-neck-injury rate. Moreover, after classifying the 760 persons in Table 3 separately according to each factor, additional analyses were conducted for the sake of reference.

The results of a comparison of the no-neck-injury rate according to the presence of an AHR in each group into which the 760 persons were divided on the basis of pseudo-ΔV are shown in Figure 13. It is seen that the no-neck-injury rate with an AHR was statistically higher than that without an AHR for the 0-10km/h group and the 11-20km/h group that accounted for the majority of the 760 persons. It was significantly higher at the 5% significance level for the 0-10km/h group. For the 11-20km/h group, it was significantly higher at the 1% significance level. As for the 21-30km/h group, it is observed that the no-neck-injury rate with an AHR was higher than that without an AHR, but no statistically significant difference can be confirmed because of the limited data. As a whole, it can be concluded that the no-neck-injury rate with an AHR was higher than that without an AHR even when the influence of the impact severity in the collision was eliminated.

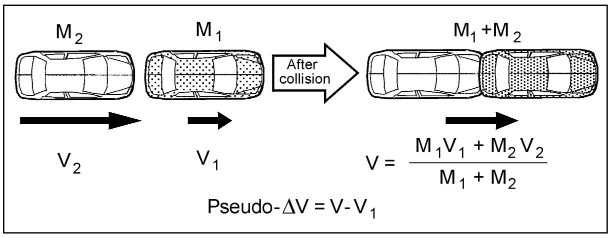


Figure 12: Definition of pseudo-ΔV

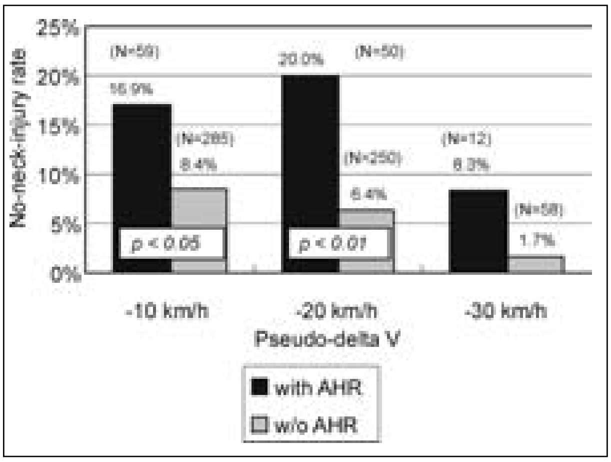


Figure 13: Influence of AHR on no-neck-injury rate by pseudo-ΔV

Figure 14 presents the results for the no-neck-injury rate when a comparison was made by gender in relation to the presence of an AHR, after the 760 persons were distinguished by gender. For males, it was confirmed that the no-neck-injury rate with an AHR was higher than that without an AHR at the 1% significance level. As for females, the no-neck-injury rate with an AHR was higher than that without an AHR, though no statistically significant difference can be confirmed because of the limited data. Overall, it can be inferred that the no-neck-injury rate with an AHR was higher than that without an AHR even after excluding the influence of gender.

Figure 15 shows that the no-neck-injury rate with an AHR was higher than that without an AHR for each age group into which the 760 persons were divided according to age (Figure 11). A statistically

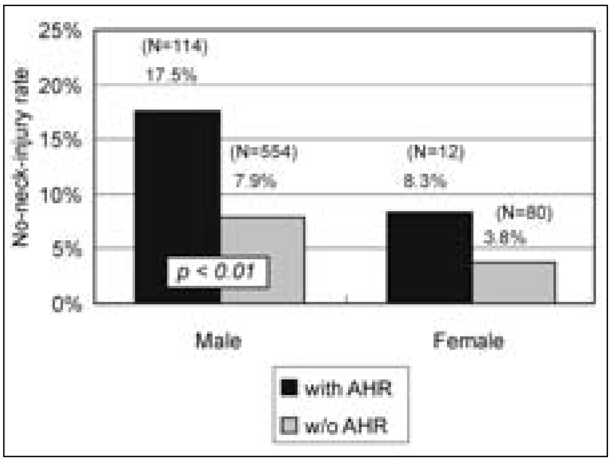


Figure 14: Influence of AHR on no-neck-injury rate by gender

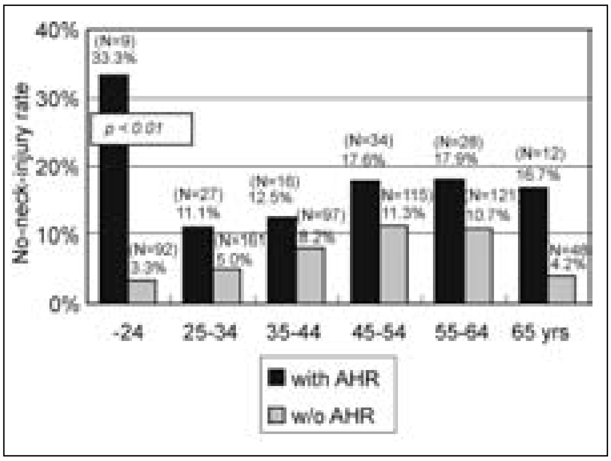


Figure 15: Influence of AHR on no-neck-injury rate by age (divided into six age groups)

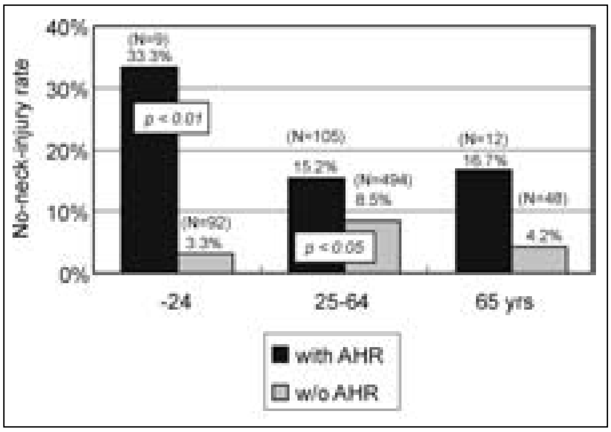


Figure 16: Influence of AHR on no-neck-injury rate by age (divided into six age groups)

significant difference was confirmed only for the 24-or-younger group at the 1% significance level, because of the limited data for the other groups. Considering the group from 25 to 64 years old, the no-neck-injury rate with an AHR was also higher than that without an AHR at the 5% significance level as shown in Figure 16. On the whole, it would appear that the no-neck-injury rate with an AHR was higher than that without an AHR even when the influence of age was removed.

Effect of an Anti-Whiplash Device – Analysis 2

Method and data

In Analysis 1, the influence of each factor was separately excluded when the no-neck-injury rate was calculated in order to analyze the effect of an AHR. A regression analysis was then conducted in which all of the factors, including the presence/absence of an AHR, were treated at the same time. As the neck injury severity is a qualitative variable and also a ranked variable, an ordered response model was used in the analysis [11]. It was decided to treat the neck injury severity as a binary response of neck injuries (fatalities, serious or slight injuries principally to the neck) or no injuries. An explanation is given here of the method for conducting a regression analysis using an ordered response model. With an ordered response model, it is assumed that there is a latent factor Y^*_i which is a continuous variable that determines whether the neck injury severity Y_i is 1 (neck injury) or 0 (no injury). In this analysis, it is assumed that there is a linear relation between the continuous latent factor Y^*_i indicating the neck injury severity and the explanatory variables, including $X_{k,i}$ (k=1,2,3,…), pseudo-ΔV, which are considered as independent variables. Then, Y^*_i can be expressed with the following equations:

$$Y^*_i = z_i + \varepsilon_i$$

$$z_i = \beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} + \beta_3 X_{3,i} + \ldots + \beta_k \text{Pseudo}\Delta V$$

where,

$$Y_i = \begin{cases} 1 \text{ (neck injury): in the case of } Y^*_i > 0 \\ 0 \text{ (no injury): in the case of } Y^*_i \leq 0 \end{cases}$$

z_i is a value which can be explained by $X_{1,i}$, $X_{2,i}$, $X_{3,i}$,…, and pseudo-ΔV. ε_i is a residual value. $X_{1,i}$, $X_{2,i}$, $X_{3,i}$,… are explanatory variables and have a value of either 0 or 1 if they are dummy variables. β_0, β_1, β_2, β_3,…, β_k are constant values which express the degree of influence of each explanatory variable on Y^*_i. The cumulative distribution function F of $-\varepsilon_i$ is assumed to be the logistic distribution given in the following equation:

$$F = e^z / (1 + e^z)$$

Here, the explanatory factors are with/without an AHR, gender (male, female), age (24 years or younger, 25-34 years, 35-44 years, 45-54 years, 55-64 years, 65 years or older) and pseudo-ΔV. These factors, except pseudo-ΔV, are treated as dummy variables which have a value of either 0 or 1. A combination of without an AHR, male and 24 years or younger is assumed to be the standard combination, and the analysis is conducted. Concretely, k is set from 1 to 8, and $X_{1,i}=X_{2,i}=\ldots=X_{7,i}=0$ in the standard combination. $X_{1,i}=1$ with an AHR. $X_{2,i}=1$ in the case the gender is female. $X_{3,i}=1$ when the age is 25-34 years, $X_{4,i}=1$ when 35-44 years, $X_{5,i}=1$ when 45-54 years, $X_{6,i}=1$

when 55-64 years, and $X_{7,i}$=1 when the age is 65 years or older.

The data for 21 of the 760 persons extracted in Analysis 1 were omitted in this analysis because of uncertain pseudo-ΔV. The data of the remaining 739 persons were used in the regression analysis conducted with the ordered response model. The constant values of β_0, β_1, β_2, β_3,..., β_8 were estimated by the maximum likelihood method, using the TSP 5.0 statistical analysis software [12].

Results

The results of the analysis are presented in Table 4 and Figure 17. The estimated values are the results of an estimation of the coefficient β_k. A likelihood ratio test was carried out to evaluate the null hypothesis, assuming that all the estimated values were equal to 0. The 2LL result of this test was 22.85, which was statistically significant because it was larger than 20.1 of the 1% chi-square of 8 degrees of freedom. The fraction of correct predictions was 0.912. Therefore, it can be concluded that the regression equation consisting of the explanatory variables such as with/without an AHR, gender, age and pseudo-ΔV is significant.

As for the effect of an AHR, the estimated (coefficient) with an AHR was negative at -0.871, and the t-statistic was -2.97, which satisfied the 1% significance level in the two-sided test. This indicates that Y^*_i becomes smaller and that the possibility of no injury increases when an AHR is installed.

			Estimated	Std. Error	t-statistic	p-value
Constant		β_0	2.417	0.472	5.115	0
With AHR		β_1	-0.871	0.293	-2-970	0.003**
Female		β_2	0.800	0.539	1.483	0.138
Age	25-34yrs	β_3	0.108	0.537	1.483	0.138
	35-44yrs	β_4	-0.514	0.542	-0.949	0.342
	45-54yrs	β_5	-0.785	0.497	-1.579	0.114
	55-64yrs	β_6	-0.564	0.504	-1.119	0.263
	65yrs	β_7	-0.018	0.678	-0.026	0.979
Pseudo-ΔV (km/h)		β_8	0.036	0.019	1.834	0.067
Number of observations = 739			Fraction of Correct Predictions=0.912			
Log likelihood L=208.639			Log likelihood L_0=-220.063			
2LL=22.85	**: p<0.01					

Table 4: Estimated results of regression analysis using an ordered response model (without AHR, male, 24 years or younger)

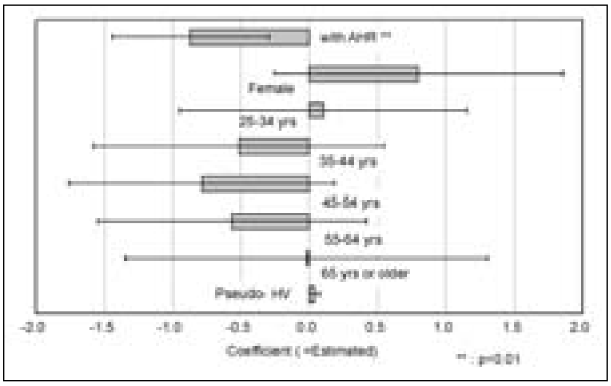


Figure 17: Coefficients and 95% confidence intervals

Conclusion

The following results were obtained in this analysis of rear-end collisions in Japan using the integrated accident database developed by ITARDA.

1. The actual situation for rear-end collisions and resultant injuries of ordinary-passenger-car occupants was clarified.
2. It was shown that the no-neck-injury rate of struck-vehicle drivers did not tend to decrease with a later initial year of registration of the struck vehicles. On the contrary, in some passenger car classes, the no-neck-injury rate tended to increase with a later initial year of registration of the struck vehicles.
3. After eliminating various factors which were thought to influence the incidence of neck injuries, it was found that an active head restraint (AHR) system, which is one type of anti-whiplash device, was effective in suppressing the incidence of neck injuries in struck-vehicle drivers, though the verification was based on just one vehicle model. The various factors eliminated were the crash characteristics of the struck vehicle, impact severity estimated from the weight and impact speed of the striking and struck vehicles, and drivers' gender, age and consciousness of whiplash.

The incidence of no injuries in property damage accidents is not reflected in the no-neck-injury rate used in this study because of limitations of the integrated accident database. The accuracy of analyses based on the no-neck-injury rate could be further improved by using a database that included the incidence of no injuries in property damage accidents such as the database of the automobile insurance industry.

Acknowledgements

The author wishes to thank Dr. Munemasa SHIMAMURA of the Chiba Institute of Science for his useful advice about conducting a regression analysis using an ordered response model.

References

[1] T. SUZUKI, K. HAGITA: Analysis of the reason the number of traffic fatalities decreased to 7,358 persons (in Japanese), Proceedings of 8th ITARDA Annual Seminar, p. 3-20, 2005

[2] K. MASHIKO, H. MATSUMOTO, Y. HARA, Y. SAKAMOTO, K. TAKEI, Y. UENO, Y. TOMITA: Present status and future perspectives of emergency medical service system for traffic accident (in Japanese), Proceedings of Society of Automotive Engineers of Japan “Challenges for making traffic fatalities and casualties zero” in GIA dialogue 2005, p. 39-44, 20054653, 2005

[3] Cabinet Office: WHITE PAPER on traffic safety in Japan 2005, 2005

[4] H.J. MERTZ, L.M. PATRICK: Strength and Response of the Human Neck, SAE 710855, 1971

[5] T. MATSUSHITA, T.B. SATO, K. HIRABAYASHI: X-Ray Study of the Human Neck Motion Due to Head Inertia Loading, SAE 942208, 1994

[6] K. ONO, K. KANEOKA, A. WITTEK, J. KAJZER: Cervical injury mechanism based on the analysis of human cervical vertebral motion and head-neck-torso kinematics during low speed rear impacts, SAE 973340, 1997

[7] O. BOSTROM, M.Y. SVENSSON, B. ALDMAN, H.A. HANSSON, Y HALAND, P LOVSUND, T SEEMAN, A. SUNESON, A. SALJO, T. ORTENGREN: A new neck injury criterion candidate – based on injury findings in the cervical spinal ganglia after experimental neck extension trauma, Proceedings of 1996 International IRCOBI conference on the Biomechanics of impact, p. 123-136, 1996

[8] M.Y. SVENSSON, B. ALDMAN, H.A. HANSSON, P. LOVSUND, T. SEEMAN, A. SUNESON, T. ORTENGREN: Pressure effects in the spinal canal during whiplash extension motion; A possible cause of injury to the cervical spinal ganglia, Proceedings of 1993 International IRCOBI conference on the Biomechanics of impact, p. 189-200, 1993

[9] Japan Automobile Manufacturers Association, Inc. (JAMA): Aim at safe car society (in Japanese), http://www.jama.or.jp/safe/safe_eco_digest/safe_eco_digest_05.html

[10] M. SHIMAMURA, M. YAMAZAKI, G. FUJITA: Method to evaluate the effect of safety belt use by rear seat passengers on the injury severity of front seat occupants, Accident Analysis and Prevention, Vol. 37, issue 1, p. 5-17,2005

[11] K. NAWATA, Probit Logit Tobit, A. MAKI et al.: Applied econometrics II (in Japanese), Section 4, p. 237-270, Taga-Shuppan, 1997

[12] TSP Japan: Guide for TSP 5.0, 2005

J.S. Jermakian
Center for Injury Research and Prevention, The Children's Hospital of Philadelphia, Philadelphia, USA

Injuries to Child Pedestrians Admitted to an Urban Pediatric Trauma Center

Abstract

This study examines the severity and types of injuries sustained by child pedestrians aged 18 years and below in order to identify the body regions at greatest risk for injury in a pedestrian accident. Detailed medical diagnoses were reviewed retrospectively for 572 child pedestrians admitted to an urban pediatric trauma center with injuries during the time period from January 2001 to December 2005. Eighty percent of these children sustained AIS 2 or greater injuries, most commonly to the lower extremity (41%) and head (34%). Forty-four percent of admitted children had more significant AIS 3 or greater injuries primarily to the head (58%), thorax (17%) and lower extremities (14%). Testing procedures to assess the child's interaction with the motor vehicle should include injury assessment for the pediatric head, thorax and lower extremities. This understanding of how child pedestrians interact with motor vehicles may provide insight into effective countermeasures with potential for implementation in vehicle designs world-wide.

Notation

CHOP The Children's Hospital of Philadelphia

AIS Abbreviated Injury Scale

Introduction

An estimated 1.2 million traffic fatalities occur per year world-wide and an additional 20 to 50 million people are injured. The rates of death and injury are highest for low and middle income countries and these rates are expected to increase without appropriate interventions. Vulnerable road users such as pedestrians are at particular risk of death and injury [1]. While low and middle income countries show the greatest pedestrian fatality rates, all countries demonstrate the need to protect vulnerable road users. In the United States in 2004, more than 10 percent of all traffic fatalities were pedestrians, accounting for more than 4,600 deaths per year. Of the pedestrian fatalities, more than 8 percent were children under the age of 16. When considering injured pedestrians, children under 16 years old account for more than 29 percent of all injured pedestrians [2]. Since children offer a unique design challenge because of their small stature and stage of development, an understanding of the most prevalent and serious injuries they sustain is a critical first step before appropriate countermeasures can be designed.

Previous studies have examined this issue using trauma registry data from hospital admissions between 1988 to 2003 [3-5]. These studies identified the head and external soft tissue injuries as the most common when considering all injury severities [4, 5]. When only severe injuries are considered, the head is still the most frequently injured body region, followed by the lower extremities, then thorax [5]. This current study builds on this previous work and with a more recent data set, examining the severity and types of injuries sustained by child pedestrians aged 18 years and below in order to identify the body regions at greatest risk for injury in a pedestrian accident. These data provide insight into the injuries children are currently sustaining, particularly as the vehicle fleet in the United States changes to include vehicles with a higher center of gravity and more aggressive frontal planes, such as sport utility vehicles and light trucks.

Methods

Detailed clinical data were obtained from all children aged 0-18 years admitted to the Children's Hospital of Philadelphia (CHOP) from January 2001 to December 2005 as a result of injuries sustained as a pedestrian struck by a motor vehicle. CHOP is a Level 1 Pediatric Trauma Center and is situated in an urban setting of 5.2 million people. The data were collected through the CHOP Trauma Registry, an electronic database of detailed medical diagnoses, procedures, and clinical data of all children admitted to the trauma program at the hospital. Specific medical diagnoses based on Abbreviated Injury Scale (AIS) codes were documented for each case. These codes provided a detailed description of the injury diagnoses through a structured coding system and are available for each child as part of the standard data collected in the trauma registry. These data were then analyzed to determine the distribution of injuries by body region and age. The Institutional Review Board at CHOP approved of this retrospective review of clinical data.

Results

Detailed medical diagnoses were reviewed retrospectively for 572 child pedestrians admitted to CHOP during the time period from January 2001 to December 2005. The children ranged from 0 to 18 years in age (average: 8.6 years) and 65% were male. Age 7 was most common pedestrian age and children aged 4 to 7 years accounted for more than a third of all pedestrians. Figure 1 shows the age and gender distribution of the child pedestrians.

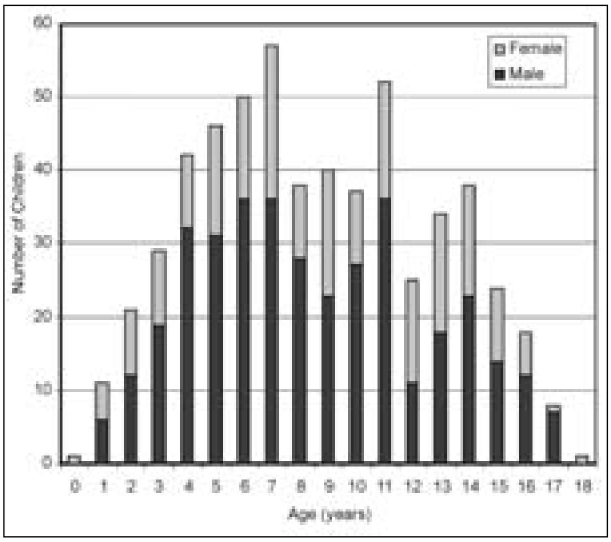


Figure 1: Age and gender distribution of all child pedestrians admitted to CHOP from 2001 to 2005

The 572 children sustained a total of 2,625 injuries; 53% of these injuries were AIS 2 or greater and 23% were AIS 3 or greater. Table 1 shows the distribution of all injuries for all ages by body region. The head accounted for 30% of all injuries, followed by the lower extremity (27%) and the face (18%).

Eighty percent of the child pedestrians sustained AIS 2 or greater injuries, most commonly to the head (41%) and lower extremity (34%). On average, these children sustained 3.0 AIS 2 or greater injuries to 1.5 body regions. Table 2 shows the body region distribution of the AIS 2 and greater injuries (n=1,391) stratified by age of the child. When examined by age groups, the patterns of injury for each group were similar to the overall body region distribution in which the head was the most commonly injured body region followed by the lower extremities for all ages 2 and older.

Forty-four percent of admitted children had more significant AIS 3 or greater injuries primarily to the head (58%), thorax (17%) and lower extremities (14%). On average, these children sustained 2.4 AIS 3 or greater injuries to 1.3 body regions. Table 3 shows the body region distribution of the AIS 3

Body Region	Injuries, n=2,625
Head	786 (30%)
Face	470 (18%)
Neck	8 (0%)
Thorax	143 (5%)
Abdomen	137 (5%)
Spine	20 (1%)
Upper Extremity	241 (9%)
Lower Extremity	702 (27%)
Whole Area	117 (4%)
Unknown	1 (0%)

Table 1: Distribution of all injuries (n=2,625) for all children aged 0 to 18 years old

	Child Age in Years						
Body Region	<2	2-3	4-6	7-9	10-12	13+	All Ages
Head	7 (41%)	40 (43%)	143 (44%)	137 (41%)	102 (39%)	136 (38%)	565 (41%)
Face	0 (0%)	5 (5%)	14 (4%)	22 (7%)	21 (8%)	13 (4%)	75 (5%)
Neck	0 (0%)	0 (0%)	0 (0%)	1 (0%)	0 (0%)	1 (0%)	2 (0%)
Thorax	5 (29%)	9 (10%)	24 (7%)	23 (7%)	15 (6%)	29 (8%)	105 (8%)
Abdomen	1 (6%)	10 (11%)	11 (3%)	14 (4%)	11 (4%)	20 (6%)	67 (5%)
Spine	0 (0%)	1 (1%)	6 (2%)	2 (1%)	1 (0%)	6 (2%)	16 (1%)
Upper Extremity	1 (6%)	9 (10%)	15 (5%)	18 (5%)	19 (7%)	23 (6%)	85 (6%)
Lower Extremity	3 (18%)	18 (20%)	112 (34%)	114 (34%)	93 (35%)	133 (37%)	473 (34%)
Whole Area	0 (0%)	0 (0%)	2 (1%)	0 (0%)	0 (0%)	1 (0%)	3 (0%)

Table 2: Distribution of AIS 2 and greater injuries (n=1,391) by child age

and greater injuries (n=606) stratified by age of the child. When examined by age group, the head was the most common injured body region followed by the thorax then lower extremity for all ages under 10 years old. For children 10 to 12 years, the thorax and lower extremity had similar frequencies of AIS 3 and greater injuries while the oldest children (13+ years) more frequently sustained lower extremity injuries.

The head is the most commonly injured body region for all age groups when considering all injury severity levels. Table 4 shows the types of AIS 2 and greater head injuries by age. For all ages, concussion or brief loss of consciousness (AIS 2) accounts for 27% of all AIS 2 and greater head injuries. Longer periods of unconsciousness are categorized as greater values on the AIS scale: AIS 3=3%, AIS 4=<1%, AIS 5=2%. More serious brain

	Child Age in Years						
Body Region	<2	2-3	4-6	7-9	10-12	13+	All Ages
Head	4 (40%)	26 (59%)	92 (61%)	73 (61%)	70 (63%)	89 (52%)	354 (58%)
Face	0 (0%)	0 (0%)	3 (2%)	1 (1%)	0 (0%)	1 (1%)	5 (1%)
Neck	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (1%)	1 (0%)
Thorax	5 (50%)	9 (20%)	24 (16%)	23 (19%)	15 (13%)	28 (16%)	104 (17%)
Abdomen	1 (10%)	5 (11%)	5 (3%)	6 (5%)	6 (5%)	10 (6%)	33 (5%)
Spine	0 (0%)	0 (0%)	5 (3%)	0 (0%)	0 (0%)	1 (1%)	6 (1%)
Upper Extremity	0 (0%)	1 (2%)	3 (2%)	5 (4%)	6 (5%)	3 (2%)	18 (3%)
Lower Extremity	0 (0%)	3 (7%)	18 (12%)	11 (9%)	15 (13%)	38 (22%)	85 (14%)

Table 3: Distribution of AIS 3 and greater injuries (n=606) by child age

	Child Age in Years						
	<2	2-3	4-6	7-9	10-12	13+	All Ages
Skull fracture	1	8	29	27	23	17	105
Vault	0	3	6	8	10	6	33
Base	1	5	23	19	13	11	72
Brain Injury	2	19	74	56	55	69	275
Concussion/Loss of Consciousness	3	13	39	54	23	50	182
AIS 2	2	10	32	50	20	37	151
AIS 3	0	2	3	2	2	10	19
AIS 4	1	0	1	0	0	1	3
AIS 5	0	1	3	2	1	2	9
Whole Area	1	0	0	0	1	0	2

Table 4: Distribution of AIS 2 and greater head injuries (n=564, excludes 1 unknown) by child age

	Child Age in Years						
	<2	2-3	4-6	7-9	10-12	13+	All Ages
Skeletal – Bones	3	17	107	107	90	117	441
Pelvis	1	2	24	18	7	33	85
Femur	0	6	37	31	18	15	107
Patella	0	0	0	0	0	1	1
Tibia/Fibula	2	8	44	57	54	66	231
Foot	0	1	2	1	11	2	17
Skeletal – Joints	0	0	2	5	1	10	18
Knee	0	0	1	3	1	8	13
Ankle	0	0	1	2	0	2	5
Muscles/Tendons/ Ligaments	0	0	1	1	0	5	7
Vessels	0	0	2	0	0	0	2
Other	0	1	0	1	2	1	5

Table 5: Distribution of AIS 2 and greater lower extremity injuries (n=473) by child age

	Child Age in Years						
	<2	2-3	4-6	7-9	10-12	13+	All Ages
Skeletal – Rib Cage	1	1	1	3	1	3	10
Internal Organs	4	8	23	18	14	24	91
Lung	2	4	14	7	8	13	48
Hemo/ pneumothorax	2	4	8	11	6	11	42
Diaphragm	0	0	1	0	0	0	1
Vessels	0	0	0	2	0	1	3

Table 6: Distribution of AIS 3 and greater thorax injuries (n=104) by child age

injury, which includes such intracranial injuries as hemorrhage and contusions, accounted for almost half (49%) of all AIS 2 and greater head injuries.

Table 5 outlines the AIS 2 and greater lower extremity injuries by age group. Ninety-three percent of these injuries were skeletal fractures, most commonly to the tibia/fibula (52%) and femur (24%). More clinically significant pelvic fractures accounted for 19% of these skeletal injuries.

When considering more severe injuries (AIS 3 and greater), the thorax becomes the second most injured body region accounting for 17% of the injuries for all children. Table 6 shows the types of thorax injuries sustained by age group. More than 87% of these thoracic injuries were to the internal organs, just over half of which were to the lungs.

Discussion

This analysis examined 572 children admitted to an urban pediatric trauma center and outlined the body regions injured. For all age groups, head was the most commonly injured body region at all levels of injury severity. Brain injuries such as intracranial contusion or hemorrhage composed the largest percentage of these injuries. These findings are in agreement with previously published studies [3-5]. Prevention of head injuries are particularly relevant as the effects of traumatic insult to the nervous tissue at an early age are still not fully understood and are a focus of clinical concern.

The lower extremity is the second most frequently injured body region at the less severe AIS 2 and greater injury level but 43% of the fractures are more clinically significant femur and pelvic fractures. This number is highest for the 4 to 6 year old group in which 57% of their fractures are to the femur and pelvis. While lower extremity injuries do not often present a threat to life, they can be devastating to growth and development, having significant long-term implications for the children and their families. These injuries often result in long term disability and impairment at an equal or greater extent than similar severity injuries to other body regions [6, 7]. This is an even greater concern for the pediatric population, not only because of the young age in life in which these injuries occur but also because of developmental stages of the pediatric population.

When considering more severe injuries (AIS 3 and greater), the thorax is the second most frequently injured body region for all children under 12 years old. These injuries were most often to the internal organs, specifically the lung contusions (46%) and hemo-pneumothorax (40%). Of interest, the mechanical structure of the pediatric thorax is quite different from that of an adult. Fusion of the bones of the sternum and calcification of the costal cartilage continues well into the teenage years. As a result of these changes, the overall flexibility of the pediatric thorax is substantially greater than that of an adult, contributing to the predominance of internal organ injuries over rib fractures.

The injuries seen in this data set are similar to those reported by others, despite the newer period of study, which may contain vehicles of higher and more aggressive front-end designs such as sport utility vehicles. However, since limited crash details are available in the trauma registry data, it is not possible to extract the striking vehicle type.

While this analysis shows the distribution of injuries to child pedestrians, several limitations must be considered. Children included in the trauma registry data set are admitted to an urban pediatric trauma center and represent the most seriously injured children in a geographical region. Many children with less clinically significant injuries may not be admitted to the trauma program and instead may be discharged directly from the emergency room. In addition, CHOP serves as a referral hospital for much of the surrounding area and many trauma cases are transfers from an outside hospital, contributing to the more serious nature of the injuries admitted to CHOP. Older children and adolescents may be admitted to non-pediatric trauma centers and may not be represented in this population. Finally, while the trauma registry data contain very detailed medical information, they do not include specific crash details such as the impact configuration or striking vehicle type. Therefore, it is not possible to separate children impacted by the vehicle front or side from those who were run over or backed over. Nor is it possible to compare children struck by sport utility vehicles and light trucks with passenger cars.

Conclusions

New technologies and test procedures focused on pedestrian friendly vehicle design are primarily targeted at adults and their interaction with the vehicle but the large number of injuries to child pedestrians highlights the importance of incorporating their experience in these designs. Testing procedures to assess the child's interaction with the motor vehicle should include injury assessment for the pediatric head, thorax and lower extremities. This understanding of how child pedestrians interact with motor vehicles may provide insight into effective countermeasures with potential for implementation in vehicle designs worldwide.

References

[1] World Health Organization: World report on road traffic injury prevention: summary. 2004, World Health Organization: Geneva

[2] National Center for Statistics and Analysis: Traffic Safety Facts – Pedestrians. 2004, National Highway Traffic Safety Administration: Washington, D.C

[3] D. DEMETRIADES, et al.: Pedestrians injured by automobiles: relationship of age to injury type and severity. Journal of the American College of Surgeons, 2004. 199 (3), pp. 382-7

[4] R.Y. PENG, F.S. BONGARD: Pedestrian versus motor vehicle accidents: an analysis of 5,000 patients. Journal of the American College of Surgeons, 1999. 189 (4), pp. 343-8

[5] W. WOODS, et al.: A review of pediatric pedestrian injuries at a level 1 trauma center. In: 18th International Technical Conference on the Enhanced Safety of Vehicles. Nagoya, Japan, 2003

[6] A.R. BURGESS, et al.: Lower Extremity Injuries in Drivers of Airbag-Equipped Automobiles: Clinical and Crash Reconstruction Correlations. Journal of Trauma-Injury Infection & Critical Care, 1995. 38 (4), pp. 509-516

[7] E.J. MacKENZIE, et al.: Functional Recovery and Medical Costs of Trauma: An Analysis by Type and Severity of Injury. Journal of Orthopaedic Trauma, 1988. 28 (3), pp. 281-97

W. Schneiders, S. Rammelt, A. Biewener,
M. Holch, H. Zwipp
Department of Trauma and Reconstructive Surgery, University Hospital Carl Gustav Carus, Dresden, Germany

A. Rollow, A. Serra, D. Roesner
Department of Paediatric Surgery, University Hospital Carl Gustav Carus, Dresden, Germany

S. Richter, B. Schlag
Department of Transport Science Friedrich List, Chair for Traffic and Transportation Psychology, Dresden University of Technology, Dresden, Germany

Evaluation of Risk Factors for Accidental Injuries in Children and Adolescents

Abstract

The primary goal of this investigation was to determine the relative risk of traffic accidents in students. In a two year period, a survey amongst 2,325 students was carried out, and 3,645 injuries sustained by students treated at our hospital were analyzed. Moped-riding in adolescents were associated with a 23.75-fold increased risk for injury as compared to biking. Children who ride bicycles have a 2.2-fold increased risk for an injury sustained by traffic accidents compared to pedestrians. None of 50 injured bicycle riders with helmet had an AIS for head injuries of more than 2. 24 of 233 injured bicycle drivers without helmet had an AIS for head injuries of more than 2. The use of a protective helmet significantly reduced the severity of head injuries. The level of awareness towards danger and a history of previous accidents correlate with the likelihood of future accidents. Due to the severity of traffic accidents, more adequate prevention measures (wearing of bicycle helmets and better education for moped riders) are urgently needed.

Introduction

Injuries are the most prominent health problems that young people face during school-going years. They are the leading cause of death among youth. Each year in Germany alone 300 to 400 children under the age of 15 suffer a fatal injury [1]. Between 47% and 60% of Canadian youth experienced at least one injury per year that required medical treatment [2].

However, data on injuries only provide valid information on the actual risk of each injury causing activity when taken into consideration the relationship with actual activity exposure data [3, 4]. Hence, the primary goal of this investigation was to determine the relative risk of traffic injuries in children and adolescents. We also considered the influences of social and personal risk parameters which led to the injury and which may also influence the subsequent recovery process.

Materials and Methods

Two different surveys were linked together to make a differential analysis of injuries in the region of Dresden, Germany.

Medical Survey: In the period between 01.01.1999 to 31.12.2001 a total of 3,645 injured children and adolescents were treated in the Surgical Emergency Department of the University Hospital Dresden. Data were acquired only after written informed consent of the parents.

The following data were evaluated: personal, social, medical, psychological and injury describing variables.

School Survey: 2,325 children (from 6 to under 15 years old) and adolescents (from 15 to under 18 years old) and respective parents were interviewed and questioned about leisure behaviour, living and housing settings, and history of injuries in the past three years. The sample size was calculated after the following formula $n=u^2 \times p \times (100 - p) / e^2$ [5].

Statistical Analysis

All statistical analyses were performed using a SPSS for Windows Software (SPSS 10.0, Chicago, Ill., USA). Statistical significance was assumed at $p<0.01$ for the employed Chi-square test and F-test.

An exposure-dependent risk factor was calculated through a ratio of: injury (%)/activity (%) [percentage of injuries caused by a specific activity within all injuries (data from the medical survey) divided by the percentage of a specific activity within all activities (data from the school survey)].

The ratios among the risk factor are relative risks, making it possible to derive relative risks for all studied activities. Ratios of more than one indicate an increased relative risk for injury, while ratios less than one a below average relative risk for injury. The population of both surveys were nearly identical.

Results

Injuries in children and adolescents (Medical Survey)

620 (17%) out of 3,645 patients were admitted into the hospital and 3,025 (83%) were treated as out-patients. The most frequent diagnosis of the hospitalized patients was a cerebral concussion in 211 cases (34%), followed by fractures of the lower extremity in 118 cases (18.5%). The most frequent diagnosis of the outpatients was a contusion of the upper extremity in 635 cases (21.3%) followed by fractures of the upper extremity and contusions of the lower extremity (454 cases each, 14.9%). Males (n=2187) aged 6 to 17 suffered significantly ($p<0.01$) more injuries than females (n=1,458).

36 out of 3,645 patients had been seriously injured (ISS over 13). The most frequently injured body part was the head (83.3%), followed by the thorax (63.9%), upper extremities (36.1%), and abdomen (30.6%). 30 patients suffered an injury from traffic accidents and six by from fall height.

Injury-describing variables (Medical Survey)

43% (n=1,567) of all injuries occurred during leisure time and 41% (n=1,495) of all injuries happened on the way to or from school, or at school itself. 35% of the school related injuries occurred during physical education classes, 32% happened during other curricular activities or during the breaks, 17% during after-school-care for children.

Altogether 8% of all injuries were traffic related and 8% happened at home. 59% of the accidents occurred outside and 41% within buildings. The temporal distribution of the accidents over the day showed an increased frequency between 5p.m. and 7p.m.. A quarter of all accidents occurred in these two hours. The seasonal distribution showed a relatively increased frequency of accidents in spring and summer; whereby August represents an exception (summer holidays in Saxony).

Injury risk in traffic (Medical Survey and School Survey)

Children

There is a significant age-dependent shift in the manner in which our sample population (School Survey) uses roadways. 94% of all children are daily pedestrians or walk at least several times a week. 16% of the 6 to 9 years-old, 32% of the 10 to 14 years-old children and 28.1% of the adolescents used their bicycle as means of locomotion. Public transportation is used daily by 34% of the 10 to 14 years-old children. Younger children tend to be driven by car on a daily basis (31% of the children between 6 to 9 years). Children who ride bicycles have a 2.2-fold increased risk for an injury sustained by traffic accidents compared to pedestrians [7]. The exposure dependent risk factors are shown in Figure 1.

Adolescents

There were several significant gender related differences among adolescents (School Survey). Females aged 14-17 were more often pedestrians, users of public transportation, or driven by car than males at the same age ($p<0.01$).

127 out of 601 young males used their bicycles and 21 their motor bicycles (moped) for daily travel.

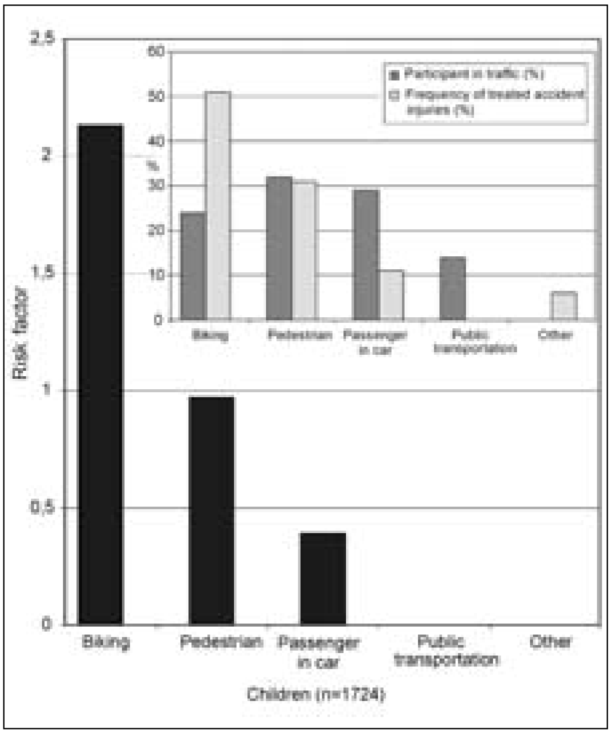


Figure 1: Exposure dependent risk factor for children in traffic

Only 3.5% of all adolescents were motorized road users. One third of all traffic related injuries comprised adolescents operating mopeds or motorcycles, thus there was a 21.1-fold increased risk for suffering an injury on the road when travelling by motorcycle or moped compared to pedestrians. Adolescents as cyclists faced a 3.7-fold increased risk of having a traffic related injury relative to pedestrians. The use of public transportation brought about the smallest risk for injury [6]. The exposure dependent risk factors are shown in Figure 2.

Bicycle accidents (Medical Survey)

283 patients suffered an injury after an accident as a bicycle rider. 233 of them did not wear a bicycle helmet at the time of injury. 24 out of these 233 patients suffered a head injury with an AIS of more than 2 points. None of 50 injured bicycle drivers with helmet had an AIS for head injuries of more than 2. The use of the bicycle helmet significantly reduced the severity of head injuries (p<0,01). 71% (n=202) of all (adolescents and children) injured cyclists were treated as out-patients. The average ISS of all hospitalized patients was 6.5. The most frequent diagnosis of the out-patients was a contusion in 81 cases and of the hospitalized patients, cerebral-contusion in 24 cases followed by fractures of the upper extremity in 24 cases.

Use of protective wear (School Survey)

There is a significant age-dependent shift in the manner in which the sample population (School Survey) uses protective wear. 55.5% (297 of 536) of children between 6 and 9 years were using a protective helmet when riding the bike. In contrast only 14% of adolescents wore a protective helmet.

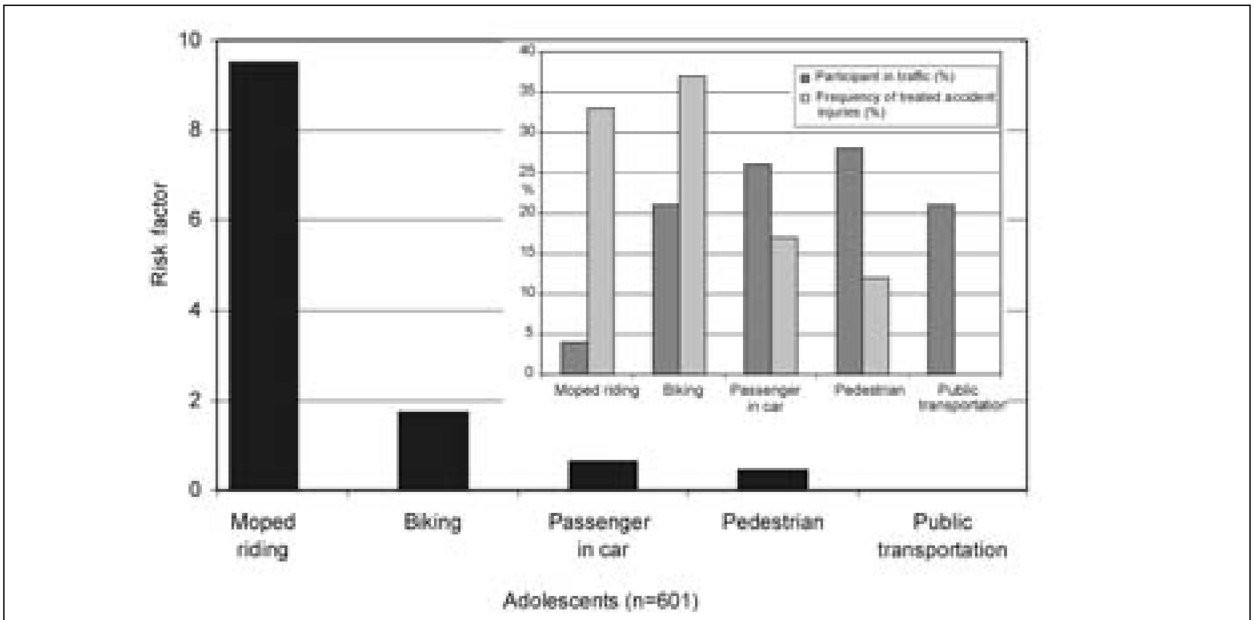


Figure 2: Exposure dependent risk factor for adolescents in traffic

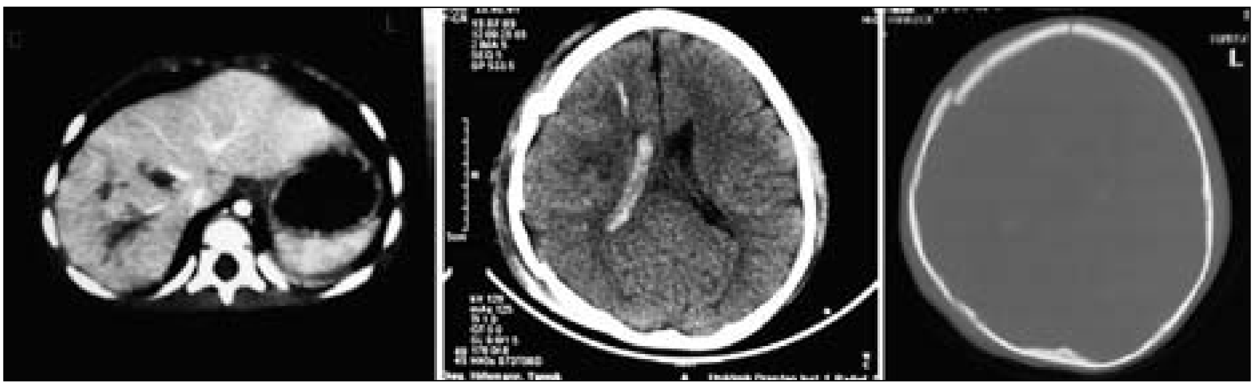


Figure 3: Year old boy after an accident as bicycle driver with a skull fracture, intracerebral haemorrhage and a rupture of the liver

With increasing age, the readiness of using protective head wear was significantly lower (p<0,01). There were no significant gender dependent differences.

Influence of physiological conditions (School Questioning)

A variance analysis was performed in order to examine the following measured variables: 'skills', 'practice in activity' that led to an accident, 'impaired hearing or vision', 'chronic illnesses' and their influence on the accident frequency. 'Age' and 'gender' were included as co-variables. The rounded results of the F-tests and the significance tests showed that children and adolescents with impaired vision had on average more injuries which needed medical treatment (p<0.01). Particularly, children and adolescents who had been described by their parents as clumsy were increasingly involved in accidents which needed medical treatment. Gender-specific influences could not be found in any of these physiological variables.

Psychological conditions		Gender			
	F=	p=	F=	p=	n
Concentration	0.80	0.50	4.93	0.03	2,245
Willingness to take risks	7.28	0.00	7.11	0.01	2,272
Independence	7.83	0.00	0.22	0.64	2,315
Activity	3.46	0.01	0.01	0.91	2,309
Behaviour while facing difficulties	3.34	0.01	0.97	0.32	2,251
Attribution of failures	0.71	0.40	7.91	0.01	2,108
Emotional impairment	0.26	0.85	2.46	0.12	2,092

Table 1: Variance-analytic (F=F-test; p=significance) investigation of the influence of psychological conditions on the accident frequency: The variables 'age' and 'gender' were included as co-variables into the analyses of variance. The variables 'willingness to take risks' and 'independence' show a highly significant influence on the frequency of accidents. Children and adolescents who were described by their parents as highly prepared to take risks had already had considerably more accidents that needed medical treatment than children and adolescents with little willingness to take risks. Additionally it was obvious that those children and young people who were described by their parents as totally dependent also showed a highly increased accident frequency

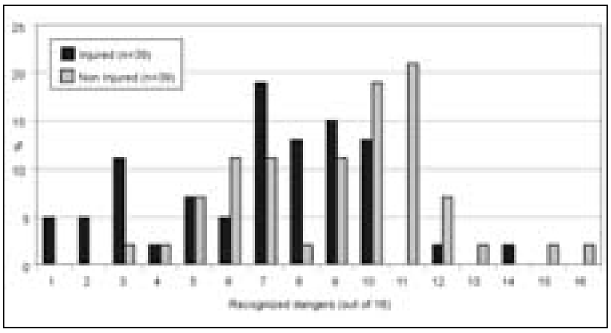


Figure 4: For a danger awareness test for children and adolescents who have suffered more than two injuries and who did not suffer any injury (control group) in the last three years an in-pair comparison was carried out. All children were shown 16 potential dangerous situations which could lead to injuries. Age- and gender-matched children and adolescents with no history of injury in the past three years recognized significantly more potential sources of danger situations [6]

Influence of the child's environment (Medical Survey)

In this segment, the influence of factors such as 'apartment size', 'whether or not the person had his/her own room', 'parents' occupation' and 'number of persons in the household' were examined. No influence on the accident frequency could be inferred from housing conditions, parents' occupation or family size of the examined children and adolescents. For example 5.7% of the children (n=59) of parents with a low occupational qualification (n=1,031) suffered 3 or more former accidents, which needed medical treatment, while it was 5% of the children (n=23) of parents with a high occupational qualification (n=463).

Discussion

The comparison of different studies of accidents in children and adolescents is quite difficult because of different age delimitations [5]. Many authors evaluate the accidents from toddlers up to adolescents altogether [3, 6, 7]. Due to the fact that the types of injury and accidents differ significantly between different age groups [8, 9, 10], we hereby tried to take a different look concerning the age and the age-dependent behaviour of children and adolescents. Certainly, we take into consideration that there were different data collection methods and different legislation in various countries. Economic aspects also play an important role and influence in the types of accidents [2].

In our investigation, the most frequent injuries were contusions and fractures of the upper extremity. Similar results are shown by many other researches [3, 7]. As an example, an investigation of twelve paediatric emergency departments in Mexico City reported that the most common injuries were open wounds followed by fractures of the fore arm [9]. With regard to the localization of injuries as reported by several authors, the relative increase in trauma of the upper extremities with an increase in age is well established.

Although some studies on accidents in young children (p to 8 years-old) showed that injuries of the head were most frequent [9, 11], other authors reporting on accidents in older children showed that injuries of the upper extremities were most common [6, 1]. We concur with both these data series. The findings of a study by READING [12] suggested that children from families with three or more children are more prone to accidents than those from smaller families. This, however, was not corroborated by our data. In our investigation, family size did not have any influence on the accident frequency.

Similarly to the series of HAYNES et al. [13], we have also observed that males had significantly more accidents than females. Boys often engage in more physically active games and take more risks than girls. Moreover, the higher number of accidents is due to the choice of hazardous activities: in fact, when comparing both genders in the same context, boys choose the same activities but carry them out in more hazardous ways [14]. The gender specific difference may be due to the influence of the parents and how they have been educated. In particular, parents encourage boys to take part in games requiring physical activity, while girls are encouraged towards safer and calmer activities [15].

Personal traits, such as the constant search for new and stimulating activities, play a fundamental role in children's behaviour in relation to hazards. In children between 6 and 8 years of age, this personal trait is a good forewarning of hazardous behaviour [16]. Other research studies have labelled those children who display aggressive, impulsive, hyperactive and stubborn behaviour as "accident phone" and hence they have a higher probability of personal injury [15, 17]. We can confirm this with our data.

A particularly relevant factor, as the basis of a person's behaviour, is the personal experience with risk. A longitudinal, 5-year study [18] on more than 10,000 children, has shown that: 1. children who had three or more accidents between birth and age of 5 were 5.9-fold more likely to have accidents between the age of 5 and 10 years, compared to those who had never had any accident before school age, 2. children who had one or more accidents requiring hospitalisation before the age of 5 years, were 2.5-fold more likely to have one or more accidents requiring hospitalisation between the age of 5 and 10. An analysis of data has confirmed that the number of previous accidents in children under the age of 5 is the best predictor of future accidents between the age of 5 and 10 years. In our investigation, the level of danger awareness was significantly lower in children with a frequent history of accidents.

Between 5.6% [19] and 8.0% (own data) of all treated injuries in children and adolescents were caused by a traffic accident. In both investigations, 39% of the children were involved as bicycle riders. According to the Federal Statistical Office of Germany, in the year 2000 alone 15,119 children suffered an accident as a bicycle rider [1]. In the United States, each year over 50,000 children suffer a bicycle accident [10]. The use of a bicycle helmet significantly reduces the risk for a head injury [20]. Such conclusions have been confirmed by our recently published results [21]. PARKIN [22] has reported that 75% of cyclists who suffered a fatal accident would still be alive if they had worn a bicycle helmet. Accordingly, one of the challenges in the prevention of accidents is the decreasing willingness of children and adolescents in wearing a helmet as they grow older [21]. An investigation by the Federal Institution for Roads in Germany [23] showed that children at the age of 10 have the highest ratio (40%) of wearing a helmet in comparison to all other ages.

Many of the factors that appear to influence risk evaluation and appraisal – such as gender, personal traits, psychological and physiological parameters – are closely inter-related. Of all examined factors, the history of previous accidents is a predictor of future accidents. By testing the level of danger awareness, such children can be pointed out. They may then benefit from a more intensive education towards avoiding potentially dangerous situations.

Furthermore we strongly believe that due to the severity of traffic accidents, more adequate prevention measures (wearing of bicycle helmets and better education for the moped rider) are urgently necessary.

The project "Injuries of children and adolescents" was supported by the Federal Ministry for Education and Research of Germany (DLR: FKZ 01 EEC 9731/4). No conflict of interest results from this funding.

References

[1] Statistisches Bundesamt: Statistical Yearbook of Germany 2000. Wiesbaden: Metzler-Poeschel-Verlag; 2000

[2] W. BOYCE: The Health Behaviour of School Age Children: The Canadian Report. Ottawa, Ontario: Health Canada 2003

[3] C. FUNK: Unfallverletzungen bei Kindern. Thesis, University of Ulm, Germany, 1997

[4] J.A. NAVASCUES, J. MATUTE, J. SOLETO et al.: Paediatric trauma in Spain: a report from the HUGM Trauma Registry. Eur J Pediatr Surg. 2005;15(1):30-7

[5] D. MACHIN, M.J. CAMPBELL: Statistical Tables for the Design of Clinical Trials. Oxford: Blackwell Scientific Publications; 1987

[6] W. SCHNEIDERS, A. ROLLOW, S. RAMMELT et al.: Risk-inducing activities leading to accidents in a child and adolescent population of Germany. 2006 Journal of Trauma

[7] I.E. KLEMENS: Unfallursachen und Unfallfolgen im Kindesalter – eine Dokumentation zur prospektiven Unfallreduzierung. Thesis, University of Münster, 1996

[8] M.S. DURKIN, S. OLSEN, B. BARLOW et al.: The epidemiology of urban paediatric neurological trauma: evaluation of, and implications for, injury prevention programs. Neurosurgery. 1998;42:300-310

[9] M.C. HIJAR-MEDINA, J.R. TAPIA-YANEZ, R.L. LOZANO-ASCENCIO et al.: Accidentes en el hogar en ninos menores de 10 anos. Causas y consecuencias. Salud Publica de Mexico. 1992;34(6):615-625

[10] S.E. KIRSCH, N. PULLEN: Evaluation of a school-based education program to promote bicycle safety. Health Promot Pract. 2003;4(2):138-45

[11] S. SHAFI, J.C. GILBERT, F. LOGHMANEE et al.: Impact of bicycle helmet safety legislation on children admitted to a regional paediatric trauma center. Journal of Paediatric Surgery. 1998;33(2):317-321

[12] R. READING, I.H. LANGFORD, R. HAYNES et al.: Accidents to preschool children: comparing family and neighbourhood risk factors. Soc Sci Med. 1999;48(3):321-30

[13] R. HAYNES, R. READING, S. GALE: Household and neighbourhood risks for injury to 5-14 year old children. Soc Sci Med. 2003;57(4):625-36

[14] B.A. MORRONGIELLO, T. DAWBER: Toddlers' and mothers' behaviour in an injury-risk situation: implications for sex differences in childhood injuries. J Appl Dev Psychol 1998;19:625-39

[15] S.P. BAKER, B. O'NEIL, M.J. GINSBURG: The injury fact book. New York: Oxford University Press; 1992

[16] R. POTTS, I.G. MARTINES, A. DEDMON: Childhood risk-taking and injury: Self-report and informant measures. J Pediatr Psychol. 1995;20:661-8

[17] G. ZIGON, R. CORRADETTI, B. MORRA et al.: Psychological aspects of risk appraisal in asphyxiation accidents. Acta Otorhinolaryngol Ital. 2005;25:100-106

[18] P.E. BIJUR, J. GOLDING, M. HASLUM: Persistence of occurence of injury: Can injuries of preschool children predict injuries of school-aged children? Paediatrics 1988;82:707-12

[19] J. MAYR, O. RUSSE, P. SPITZER et al.: Playground accidents. Acta Paediatrica 1995;84:573-576

[20] H.R. CHAPMAN, A.L. CURRAN: Bicycle helmets – does the dental profession have a role in promoting their use? Br Dent J. 2004;196(9):555-60

[21] W. SCHNEIDERS, A. ROLLOW, S. RAMMELT et al.: Unfälle von Kindern und Jugendlichen. Unfallchirurg 2005

[22] P. PARKIN, L. SPENCE, X. HU et al.: Evaluation of a promotional strategy to increase bicycle helmet use by children. Paediatrics 1993;91(4):283-7

[23] W. SIEGENER, T. RÖDELSTAB: Continuous monitoring of road user safety behaviour [bast.de, Web site]. 1999 Available at: http://www.bast.de/htdocs/veroeffentlichung/bastinfo/info2000/info0003.htm. Acessed February 14th, 2000

Schriftenreihe

Berichte der Bundesanstalt für Straßenwesen

Unterreihe „Fahrzeugtechnik“

1993

F 1: **Einfluß der Korrosion auf die passive Sicherheit von Pkw**
Faerber, Wobben € 12,50

F 2: **Kriterien für die Prüfung von Motorradhelmen**
König, Werner, Schuller, Beier, Spann € 13,50

F 3: **Sicherheit von Motorradhelmen**
Zellmer € 11,00

F 4: **Weiterentwicklung der Abgassonderuntersuchung**
Teil 1: Vergleich der Ergebnisse aus Abgasuntersuchung und Typprüfverfahren
Richter, Michelmann
Teil 2: Praxiserprobung des vorgesehenen Prüverfahrens für Fahrzeuge mit Katalysator
Albus € 13,50

1994

F 5: **Nutzen durch fahrzeugseitigen Fußgängerschutz**
Bamberg, Zellmer € 11,00

F 6: **Sicherheit von Fahrradanhängern zum Personentransport**
Wobben, Zahn € 12,50

F 7: **Kontrastwahrnehmung bei unterschiedlicher Lichttransmission von Pkw-Scheiben**
Teil 1: Kontrastwahrnehmung im nächtlichen Straßenverkehr bei Fahrern mit verminderter Tagessehschärfe
P. Junge
Teil 2: Kontrastwahrnehmung in der Dämmerung bei Fahrern mit verminderter Tagessehschärfe
Chmielarz, Siegl
Teil 3: Wirkung abgedunkelter Heckscheiben - Vergleichsstudie
Derkum € 14,00

F8: **Anforderungen an den Kinnschutz von Integralhelmen**
Otte, Schroeder, Eidam, Kraemer € 10,50

F 9: **Kraftschlußpotentiale moderner Motorradreifen unter Straßenbedingungen**
Schmieder, Bley, Spickermann, von Zettelmann € 11,00

1995

F 10: **Einsatz der Gasentladungslampe in Kfz-Scheinwerfern**
Damasky € 12,50

F 11: **Informationsdarstellung im Fahrzeug mit Hilfe eines Head-Up-Displays**
Mutschler € 16,50

F 12: **Gefährdung durch Frontschutzbügel an Geländefahrzeugen**
Teil 1: Gefährdung von Fußgängern und Radfahrern
Zellmer, Schmid
Teil 2: Quantifizierung der Gefährdung von Fußgängern
Zellmer € 12,00

F 13: **Untersuchung rollwiderstandsarmer Pkw-Reifen**
Sander € 11,50

1996

F 14: **Der Aufprall des Kopfes auf die Fronthaube von Pkw beim Fußgängerunfall – Entwicklung eines Prüfverfahrens**
Glaeser € 15,50

F 15: **Verkehrssicherheit von Fahrrädern**
Teil 1: Möglichkeiten zur Verbesserung der Verkehrssicherheit von Fahrrädern
Heinrich, von der Osten-Sacken
Teil 2: Ergebnisse aus einem Expertengespräch „Verkehrssicherheit von Fahrrädern“
Nicklisch € 22,50

F 16: **Messung der tatsächlichen Achslasten von Nutzfahrzeugen**
Sagerer, Wartenberg, Schmidt € 12,50

F 17: **Sicherheitsbewertung von Personenkraftwagen – Problemanalyse und Verfahrenskonzept**
Grunow, Heuser, Krüger, Zangemeister € 17,50

F 18: **Bremsverhalten von Fahrern von Motorrädern mit und ohne ABS**
Präckel € 14,50

F 19: **Schwingungsdämpferprüfung an Pkw im Rahmen der Hauptuntersuchung**
Pullwitt € 11,50

F 20: **Vergleichsmessungen des Rollwiderstands auf der Straße und im Prüfstand**
Sander € 13,00

F 21: **Einflußgrößen auf den Kraftschluß bei Nässe**
Fach € 14,00

1997

F 22: **Schadstoffemissionen und Kraftstoffverbrauch bei kurzzeitiger Motorabschaltung**
Bugsel, Albus, Sievert € 10,50

F 23: **Unfalldatenschreiber als Informationsquelle für die Unfallforschung in der Pre-Crash-Phase**
Berg, Mayer € 19,50

1998

F 24: **Beurteilung der Sicherheitsaspekte eines neuartigen Zweiradkonzeptes**
Kalliske, Albus, Faerber € 12,00

F 25: **Sicherheit des Transportes von Kindern auf Fahrrädern und in Fahrradanhängern**
Kalliske, Wobben, Nee € 11,50

1999

F 26: **Entwicklung eines Testverfahrens für Antriebsschlupf-Regelsysteme**
Schweers € 11,50

F 27: **Betriebslasten an Fahrrädern**
Vötter, Groß, Esser, Born, Flamm, Rieck € 10,50

F 28: **Überprüfung elektronischer Systeme in Kraftfahrzeugen**
Kohlstruck, Wallentowitz € 13,00

2000

F 29: **Verkehrssicherheit runderneuerter Reifen**
Teil 1: Verkehrssicherheit runderneuerter Reifen
Glaeser
Teil 2: Verkehrssicherheit runderneuerter Lkw-Reifen
Aubel € 13,00

F 30: **Rechnerische Simulation des Fahrverhaltens von Lkw mit Breitreifen**
Faber € 12,50

F 31: **Passive Sicherheit von Pkw bei Verkehrsunfällen**
Otte € 12,50

F 32: **Die Fahrzeugtechnische Versuchsanlage der BASt – Einweihung mit Verleihung des Verkehrssicherheitspreises 2000 am 4. und 5. Mai 2000 in Bergisch Gladbach** € 14,00

F 33: **Sicherheitsbelange aktiver Fahrdynamikregelungen**
Gaupp, Wobben, Horn, Seemann € 17,00

2001

F 34: **Ermittlung von Emissionen im Stationärbetrieb mit dem Emissions-Mess-Fahrzeug**
Sander, Bugsel, Sievert, Albus € 11,00

F 35: **Sicherheitsanalyse der Systeme zum Automatischen Fahren**
Wallentowitz, Ehmanns, Neunzig, Weilkes, Steinauer, Bölling, Richter, Gaupp € 19,00

F 36: **Anforderungen an Rückspiegel von Krafträdern**
van de Sand, Wallentowitz, Schrüllkamp € 14,00

F 37: **Abgasuntersuchung - Erfolgskontrolle: Ottomotor – G-Kat**
Afflerbach, Hassel, Schmidt, Sonnborn, Weber € 11,50

F 38: **Optimierte Fahrzeugfront hinsichtlich des Fußgängerschutzes**
Friesen, Wallentowitz, Philipps € 12,50

2002

F 39: **Optimierung des rückwärtigen Signalbildes zur Reduzierung von Auffahrunfällen bei Gefahrenbremsung**
Gail, Lorig, Gelau, Heuzeroth, Sievert € 19,50

F 40: **Prüfverfahren für Spritzschutzsysteme an Kraftfahrzeugen**
Domsch, Sandkühler, Wallentowitz € 16,50

2003

F 41: **Abgasuntersuchung: Dieselfahrzeuge**
Afflerbach, Hassel, Mäurer, Schmidt, Weber € 14,00

F 42: **Schwachstellenanalyse zur Optimierungdes Notausstiegsystems bei Reisebussen**
Krieg, Rüter, Weißgerber € 15,00

F 43: **Testverfahren zur Bewertung und Verbesserung von Kinderschutzsystemen beim Pkw-Seitenaufprall**
Nett € 16,50

F 44: **Aktive und passive Sicherheit gebrauchter Leichtkraftfahrzeuge**
Gail, Pastor, Spiering, Sander, Lorig € 12,00

2004

F 45: **Untersuchungen zur Abgasemission von Motorrädern im Rahmen der WMTC-Aktivitäten**
Steven € 12,50

F 46: **Anforderungen an zukünftige Kraftrad-Bremssysteme zur Steigerung der Fahrsicherheit**
Funke, Winner € 12,00

F 47: **Kompetenzerwerb im Umgang mit Fahrerinformationssystemen**
Jahn, Oehme, Rösler, Krems € 13,50

F 48: **Standgeräuschmessung an Motorrädern im Verkehr und bei der Hauptuntersuchung nach § 29 STVZO**
Pullwitt, Redmann € 13,50

F 49: **Prüfverfahren für die passive Sicherheit motorisierter Zweiräder**
Berg, Rücker, Mattern, Kallieris € 18,00

F 50: **Seitenairbag und Kinderrückhaltesysteme**
Gehre, Kramer, Schindler € 14,50

F 51: **Brandverhalten der Innenausstattung von Reisebussen**
Egelhaaf, Berg, Staubach, Lange € 16,50

F 52: **Intelligente Rückhaltesysteme**
Schindler, Kühn, Siegler € 16,00

F 53: **Unfallverletzungen in Fahrzeugen mit Airbag**
Klanner, Ambios, Paulus, Hummel, Langwieder, Köster € 15,00

F 54: **Gefährdung von Fußgängern und Radfahrern an Kreuzungen durch rechts abbiegende Lkw**
Niewöhner, Berg € 16,50

2005

F 55: **1st International Conference on ESAR „Expert Symposium on Accident Research“ – Reports on the ESAR-Conference on 3rd/4th September 2004 at Hannover Medical School** € 29,00

2006

F 56: **Untersuchung von Verkehrssicherheitsaspekten durch die Verwendung asphärischer Außenspiegel**
Bach, Rüter, Carstengerdes, Wender, Otte € 17,00

F 57: **Untersuchung von Reifen mit Notlaufeigenschaften**
Gail, Pullwitt, Sander, Lorig, Bartels € 15,00

F 58: **Bestimmung von Nutzfahrzeugemissionsfaktoren**
Steven, Kleinebrahm € 15,50

F 59: **Hochrechnung von Daten aus Erhebungen am Unfallort**
Hautzinger, Pfeiffer, Schmidt € 15,50

F 60: **Ableitung von Anforderungen an Fahrerassistenzsysteme aus Sicht der Verkehrssicherheit**
Vollrath, Briest, Schießl, Drewes, Becker € 16,50

2007

F 61: **2nd International Conference on ESAR „Expert Symposium on Accident Research“ – Reports on the ESAR-Conference on 1st/2nd September 2006 at Hannover Medical School** € 30,00

Alle Berichte sind zu beziehen beim:

Wirtschaftsverlag NW
Verlag für neue Wissenschaft GmbH
Postfach 10 11 10
D-27511 Bremerhaven
Telefon: (04 71) 9 45 44 - 0
Telefax: (04 71) 9 45 44 77
Email: vertrieb@nw-verlag.de
Internet: www.nw-verlag.de

Dort ist auch ein Komplettverzeichnis erhältlich.