6th International Conference on ESAR „Expert Symposium on Accident Research“

Berichte der
Bundesanstalt für Straßenwesen

Fahrzeugtechnik Heft F 102

6th International Conference on ESAR „Expert Symposium on Accident Research“

Reports on the ESAR-Conference on 20th/21th June 2014 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

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Fahrzeugtechnik Heft F 102

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Conference Program

Hannover
Medical
School

University of
Technology
Dresden

6th International Conference ESAR

"Expert Symposium on Accident Research"

Hannover Medical School

Hannover, Germany

June 20 - 21, 2014

Conference Program

Foreword

ESAR is a scientific colloquium and can be seen as a platform for exchanges of information on accident research issues. Representatives from authorities as well as from medical and technical institutions come together to discuss new research issues and exchange experiences on accident prevention and methodologies of accident reconstruction. ESAR´s goal is to give the opportunity to all kind of studies on Accident Investigation Methodologies, Accident Analysis, Active and Passive Safety, Injury mechanisms and Injury Prevention to an audience of experts from government, industry and other researchers.

There are keynote presentations on future demands on accident research for optimisation of traffic safety and towards automated driving requirements for technology and data handling.

ESAR is fulfilling a hole with its specific information on accident data and statistical issues based on in-depth-investigation methods and got it’s position as a new trend-setting international conference for international attention.

ESAR brings together researchers from all parts of the world!

Professor Dietmar Otte

Your Host and Conference Manager

Prof. Dipl.-Ing. Dietmar Otte
Accident Research Unit
Hannover Medical School
Carl-Neuberg-Str. 1
30625 Hannover
Germany

Tel: +49 (0) 511-532-6411
Fax: +49 (0) 511 -532-6419
E-Mail: ESAR@MH-Hannover.de

http://www.esar-hannover.de

Conference Program

Organisation Commitee

Dipl.-Math. Bakker (Daimler)

Dr.-Ing. Hannawald (VUFO)

Dipl.-Ing. Jungmichel (Volkswagen)

Prof. Dr. med. Krettek (MH Hannover)

Prof. Dipl.-Ing. Otte (MH Hannover)

Prof. Dipl.-Ing. Seeck (BASt)

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Dr. Steven Ridella (NHTSA), USA

Hannover Medical School

Conference Program

Day One – Friday 20th June 2014

09:00 - 10:00

Welcome Session

Chaired by the conference manager

09:00

Welcome Introduction
Professor Dietmar Otte
Conference chairman

09:05

Welcome Notes
Professor Christian Krettek
Director Department of Trauma Surgery at Medical School Hannover

09:10

Keynote Lecture

Demands on accident research for optimization on future traffic safety
Professor Stefan Strick
President of BASt *German Federal Highway Research Institute*

09:30

Keynote Lecture

Roadmap towards automated driving-requirements for technology and data handling
Dr.-Ing. Peter E. Rieth
Head of Continental Systems & Technology Division Chassis & Safety, Germany

10:00 - 10:20

break

Conference Program

Day One – Friday 20th June 2014

10:20 - 12:00
Session: Methodology, Part 1
Chair: Seeck

10:20
Multinational In-Depth Accident Data: from concept to reality
1 Bakker
Daimler AG, Germany

10:40
Establishment of Korean KIDAS under the limited accident related data
2 Youn
Korea Tech University, South Korea

11:00
Tool for the determination of influence parameters on the accident emergence during the pre-crash phase as an enhancement of the Accident Causation Analysis System ACAS
3 Pund
TÜV Hessen, Germany

11:20
Evolution of the figures of casualties for bus/coach occupants with corresponding risk indices compared to those for occupants of cars and goods vehicles
4 Berg
DEKRA, Germany

11:40
A new methodology for determining accident and injury contributing factors, and its application to road accidents on the Mumbai–Pune Expressway
5 Patel
JP Research India PVT LTD, India

12:00 - 12:50
lunch

Conference Program

Day One – Friday 20th June 2014

12:50 - 14:30

Session: Methodology, Part 2

Chair: Bakker

12:50
In-depth study of accidents involving light goods vehicles
6 Serre
IFSTTAR, France

13:10
Cyclist-reported habits of helmet usage and differences in riding posture by using helmets
7 Jänsch
Hannover Medical School, Germany

13:30
Identification of new loadcases from the accident research
8 Gogate
Tata, India

13:50
Evaluating human-machine-interfaces for making binary choices: why measuring uncertainty is important and how to do it
9 Baier
University Regensburg, Germany

14:10
Toolbox for the benefit estimation of active and passive safety systems in terms of injury severity reduction and collision avoidance
10 Liers
VUFO, Germany

14:30 - 14:50
break

Conference Program

Day One – Friday 20th June 2014

14:50 - 16:30
Session: Assistant Systems
Chair: Schäfer

14:50
The usage of smartphones for recording accidents and incidents from the critical situation up to the post crash phase
11 Hannawald
VUFO, Germany

15:10
Investigation of the accident avoidance potential of front-camera-systems with lateral field of vision in vehicle-bicycle accidents on the basis of the GIDAS accident database
12 Uhlenhof
VUFO,Germany

15:30
Assessment of the effectivity of intersection assistance systems at urban and rural accident sites
13 Zauner
Graz University of Technology, Austria

15:50
V2X communication safety applications – Score@f project use cases
14 Chauvel
LAB, France

16:10
Effectiveness of C2X systems to avoid rear-end collisions on motorways
15 Kirchbichler
Graz University of Technology, Austria

16:30 - 16:50
break

Conference Program

Day One – Friday 20th June 2014

16:50 - 18:10

Session: Modelling and Simulation, Part 1

Chair: Hannawald

16:50
Crash simulation for Biomechanical Research
16 Johannsen
Hannover Medical School, Germany

17:10
Pregnant occupant model with a fetus for design to improve safety
17 Acar
Loughborough University, United Kingdom

17:30
Development and validation of a Lower Limb FE model using in-depth pedestrian accident cases
18 Wang
Hunan University, China

17:50
Automated crash computation of passenger car accidents based on the GIDAS database
19 Wagner
VUFO,Germany

End of first day 18:10

20:00
ESAR - Dinner
Old Town Hall, Hannover
(for further informations see Page 16)

Please use casual clothes

Conference Program

Day Two – Saturday 21st June 2014

08:30 - 09:40
Session: Modelling and Simulation, Part 2
Chair: Otte

08:30
Accident simulation and reconstruction for enhancing pedestrian safety: issues and challenges
20 Hamdane
IFSTTAR, France

08:45
UR:BAN KA-WER: Accident data analysis and pre-crash simulation for the configuration and assessment of driver assistance systems in urban scenarios
21 Labenski
Volkswagen AG, Germany

09:00
Frontal Corner Impacts – Crash tests and real-world experience
22 Dalmotas
Dalmotas Consulting, USA

09:15
Statistical driver model for accident simulation
23 Erbsmehl
Fraunhofer, Germany

09:30
Discussion Session "Modelling and Simulation"

09:40 - 10:00
break

Conference Program

Day Two – Saturday 21st June 2014

10:00 - 11:40

Session: Regulation and Consumer Aspects

Chair: Jungmichel

10:00
The current international tyre regulations cause road accidents
24 Glasner
EVU, Germany

10:15
Injury estimation for Advanced Automatic Collision Notification (AACN) in Germany
25 Lubbe
Toyota, Belgium

10:30
The characteristics of crash data in event data recorder at collision to narrow objects
26 Oga
NRIPS, Japan

10:45
Conversation with mobile phone while driving and its impact on driving behavior (The MOBIHAVE project)
27 Papadakaki
TEI Crete, Greece

11:00
Field of vision of modern cars – a study to improve the evaluation of car geometries based on real world accident scenarios within the ADAC accident research
28 Pschenitza
ADAC, Germany

11:15
Is there a broken trend in traffic safety in Germany? - Model based approach describing the relation between traffic fatalities in Germany and environmental conditions
29 Lich
Bosch, Germany

11:30
Discussion Session "Regulation and Consumer Aspects"

11:40 - 12:00 snack break

Conference Program

Day Two – Saturday 21st June 2014

12:00 - 13:40

Session: Vulnerable Road Users

Chair: Zwipp

12:00

Overview about the Project „SEEKING – SAFE E-BIKING“

30 Saleh

AIT Wien, Austria

12:15

A better understanding of single cycle accidents of elderly cyclists

31 de Hair-Buijssen

TNO, Netherlands

12:30

Did a higher distribution of pedelecs results in more severe accidents in Germany?

32 Mönnich

Bosch, Germany

12:45

Analysis of pedestrian accident leg contacts and distribution of contact points across the vehicle front

33 Barrow

TRL, United Kingdom

13:00

Comparative study of VRU head impact locations

34 Kiuchi

Toyota, Japan

13:15

Factors affecting injury risk and evaluation of biomechanical injury criterions for in-depth investigation of two wheelers accidents

35 Dias

University of Lisbon, Portugal

13:30

Discussion Session "Vulnerable Road Users"

13:40 - 14:00

break

Conference Program

Day Two – Saturday 21st June 2014

14:00 - 15:00

Session: Injury Prevention and Causation

Chair: Krettek

14:00
Injury severity resulting from accidents with reversing cars
36 Decker
Hannover Medical School, Germany

14:10
Crashes and injuries to vehicle occupants in frontal oblique crashes
37 Fildes
Monash University, Australia

14:20
Blunt lesions of the thoracic aortic vessels in trauma patients
38 Brand
Hannover Medical School, Germany

14:30
A methodology to evaluate injury risk and accident conditions from injuries in vehicle-to-pedestrian accidents
39 Francisco
University of Lisbon, Portugal

14:40
Risk of permanent impairment based on mortality?
40 Junge
Volkswagen AG, Germany

14:50
Discussion Session "Injury Prevention and Causation"

15:00

Closing Remarks

Otte
Conference Chairman

End of conference 15:10

Conference Program

Congress Office

Scientific Organisation Secretariat

Prof. Dietmar Otte
Ms. Bernadette Bruns
Carl-Neuberg-Str. 1
30625 Hannover
e-mail: Bruns.Bernadette@mh-hannover.de
+49 511 532 - 6410
during conference:
+49 176 1532 - 9992

Congress opening hours/registration desk

Friday 20th June	8:00 am – 06:30 pm
Saturday 21st June	7:30 am – 03:00 pm

Poster presentation

Some posters are displayed in the main lobby near the conference hall.

Speakers Ready Room

There is a Speakers' Ready Room near the conference hall. All Speakers are asked to provide their presentations. Please follow the signs.

Language

The official language of the Congress is English. Simultaneous translation is not provided.

Proceedings

All papers are printed in a special conference book (CD-ROM) as report of the Federal Highway Research Institute BASt Journal M with ISBN, published after the conference. We express our acknowledgement of this service!

List of Congress Hotels

Name of Hotel address	Phone Fax	Reservation	Deadline for booking	Reservation Code
Hotel IBIS Hannover Medical Park Feodor-Lynen-Str. 1 D-30625 Hannover	+49 511 95670 +49 511 9567140	www.ibishotel.com www.accorhotels.com	**15 May** 2014	ESAR
Wyndham Hannover Atrium Hotel Karl-Wiechert-Allee 68 D-30625 Hannover	+49 511 54070 +49 511 5407826	H1701@accor.com www.accorhotels.com	**15 May** 2014	ESAR
Hotel Mercure Hannover Medical Park Feodor-Lynen-Str. 1 D-30625 Hannover	+49 511 95660 +49 511 9566333	H1631@accor.com www.accorhotels.com	**15 May** 2014	ESAR

Reservations can also be done at www.hannover.de/hotels/index.html

Old Town Hall Hannover

Hannover Medical School

Travelling by car

Arriving from Kassel or Hamburg leave the highway A7 at "Autobahnkreuz Hannover-Ost" and follow the highway A2 direction "Dortmund".

Using highway A2 leave at "Autobahnkreuz Hannover-Buchholz" and follow highway A37 direction Hannover. Leave at second exit "MHH" and follow description "Medizinische Hochschule". To find the conference hall and registration desk please look at the plan on next side.

Conference Program

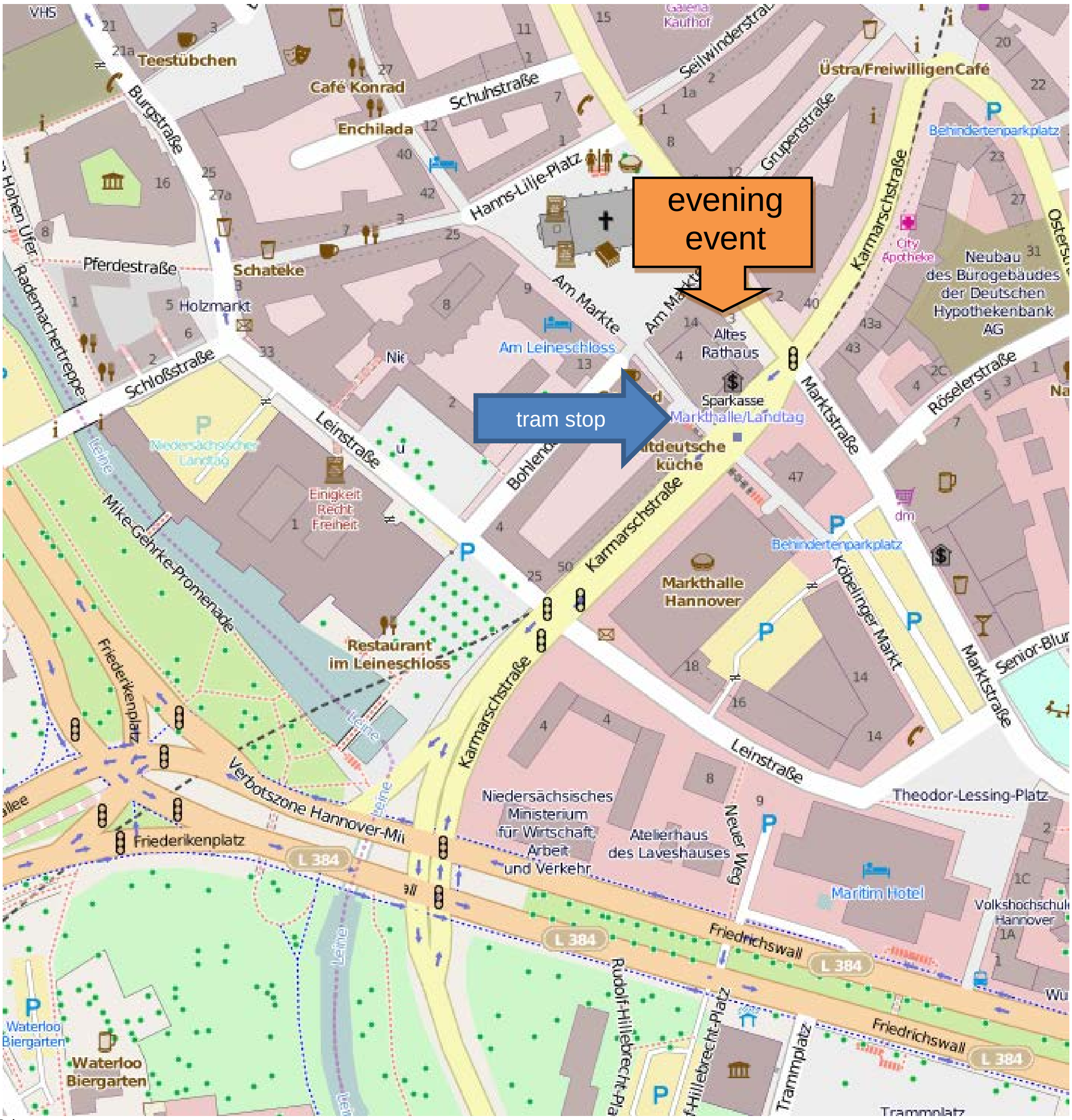
Building J1
2nd Floor
Lecture Hall F

Traveling by train
Arrival at Central Station "Hannover Hauptbahnhof".
Use Underground line 1 direction "Sarstedt" and leave the tram at station "Aegidientorplatz" (second station after entering). Use then line 4 direction "Roderbruch" from the same platform opposite side. Leave the tram at station "Medizinische Hochschule". To find the conference hall and registration desk please look at the plan at the top of this sheet.
Traveling by aeroplane
Arrival at Airport Hannover-Langenhagen. Use S-Bahn to Central Station Hannover and follow description "travelling by train" or take a taxi (approx. € 30, 20 min)

Description of way to conference hall:

5 minutes walking distance from the hotels NOVOTEL, IBIS and Mercure

Description of way to evening event



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The evening event is at “Altes Rathaus Hannover”.

To get there by tram use the line 4 direction “Garbsen” and change at “Kröpcke” to line 3 or 7 to “Wettbergen. Exit at stop called “Markthalle/Landtag”.
This is directly in front of the Old Town Hall. It takes about 20 min.

We offer a shuttle service from the conference hotels to the evening event and back.

Please note that not everybody can be transferred in time. The use of public transport services is a convenient alternative!

ESAR Support

The Organisation Committee and the Organiser, speakers, presenters and other participants gratefully acknowledge the following institutions for their various contributions in this ESAR conference:

Welcome words of the conference chairman

I am glad to welcome you in Hannover, for the 6th ESAR conference, celebrating with this conference the 10 years existing of so called “Expert Symposium on Accident Research”, 2004 was the first one. Approximately 200 papers were presented during all 5 conferences and discussed scientifically, all published as proceedings by the BAST with ISBN (international standard book number), we hope that this can be continued in the future. Thanks to BAST for the support of the printing and distribution.

ESAR should be a platform for exchange of research knowledge on data analysis and in-depth-research. The main topics are spread over a wide range of issues from regulation and consumer aspects to injury prevention and long term consequences.

Welcome to friends and to delegates from countries around the world (we accounted 19 countries). With this year’s conference we changed the time for ESAR to June. We hope to find your acceptance for this new date also for the future and are thinking this will change the problem not being any longer in conflict with other September conferences like IRCOBI, EVU, AAAM.

I know this year planning followed in conflicts for many of the attendances: Midsummer is celebrate in all northern countries exactly on these days, but we are lucky in register also some Swedish and Finnish delegates today.

Before starting the conference I would like to introduce our organizing committee and say thanks especially to the Scientific Advisory Board, which selected papers for presentation. As always we will have a scientific program with excellent keynote speakers,

Prof. Strick Federal Highway Research Institute BAST

Demands on Accident Research for Optimization on future traffic safety

Dr. Rieth Continental Systems & Technology

Roadmap towards automated driving requirements

I hope on a successful conference, thank you very much for coming!

Yours Conference Chairman

Professor Dietmar Otte

Demands on accident research for optimization future traffic safety

It is my great pleasure and honor to welcome you on behalf of the German Federal **Highway Research Institute to the 6th ESAR conference.**

This conference exists for more than 10 years already and succeeded in becoming a platform for the international exchange of knowledge on traffic accident research. It opens the opportunity for scientists from many countries to present their studies in this important research area.

Therefore I am quite happy to underline that BASt has a special relation to this conference, which was initiated in 2002 by Prof. Otte.
Prof. Otte - together with your team – you have been doing accident research on behalf of BASt for more than 40 years and you have done a great job on promoting In-Depth Accident Investigations all around the world. You are one of the best known experts in this field and I would like to take this opportunity to express my great gratitude to you and your team for all this excellent work.

We at BASt are convinced that In-Depth Traffic Investigations is one of the most cost efficient tools to further enhance vehicle and traffic safety – and - for the ministry of transport - it is an important source of knowledge for road safety policy.
Hence BASt will certainly continue contracting In-Depth Investigation together with our colleagues from the German Research Association of Automotive Engineering.

It is only two years ago that I had the opportunity to speak to you at the 5th ESAR conference. My speech was on “identifying priorities for vehicle safety”.
Vehicle safety in this regard belongs to terms of self- and partner protection. Focusing on the protection of vulnerable road users, I meant in particular the enhanced protection of pedestrians and cyclists.

When I speak about “accident research demands for future traffic safety” today, this prioritization is still valid.

Moreover – looking at the overall statistics of road traffic fatalities – the safety of pedestrians and cyclist becomes more and more important every year.

Whereas the number of road traffic victims dropped considerably during the last decade, the number of seriously and fatally injured cyclist could not drop at the same rate. It is in particular distressing that cyclists feel more and more unsafe in road traffic. This is what came out of the Cyclist Monitoring Survey 2011, where only 50% answered that they feel safe on German roads when riding a bicycle.
In 2009 it was 67% feeling safe. This downward trend should not be acceptable for a country with 70 million bicycles. It means that more efforts have to be taken to make cycling a comfortable means of transport. Besides infrastructural and behavioral aspects it is necessary to exploit technical solutions placed on motorized vehicles. In this context, I cannot retrace the discussion concerning the obligation to wear a helmet. A penalty imposed for traffic offences was needed for safety bells to become a success.
Whereas regulations play an important role, it is first of all the duty of the automobile industry to develop technical solutions and to put them on board of the vehicle fleet. This is especially true because 75% of car to cyclist accidents are caused by the passenger car; - and almost 80% of the truck to cyclist accidents are caused by the truck.

Examples of promising technical solutions can be

- systems which can avoid accidents caused by opening car doors,
- systems which assure a proper distance when overtaking a cyclists
- Autonomous Emergency Brake Systems
- Blind spot assistance for trucks

When I was talking to this audience 2 years ago, we faced a very special situation in Germany. For the first time – since the years of the German re-unification 20 years ago – the number of fatalities on German road has been increased from one year to the next.
Whereas the number of road traffic victims was 3.648 in 2010, it was more than 4.000 fatalities in 2011. This raised public concerns and some people suspected already a change of trend.

Looking at the national road traffic statistics from 2012 and 2013 we can see that those kinds of fears turned out to be baseless.
In 2013, based on estimates of BASt, 3.300 people died on German Roads. This is the lowest number of road traffic fatalities since the introduction of the statistics in 1950.
This is – however – no reason to lean back. Every day ten road users die on German Roads and more than 1000 get injured. To measure the human harm associated to these events there is no means. BASt has estimated the socio economical costs of road traffic accidents to about 30 billion Euros in 2012. This is about 1% of the German GDP.

Let me come back to the situation in early 2012, when we had to notice an increase of road traffic fatalities by 10 %. By now, we are able to explain this situation. We know that weather conditions in 2009 and 2010 had stimulated a very rapid decrease in the number of road traffic fatalities. As a result the figures of 2011 created the impression of being worse; however looking at the general trend they only have been slightly increased.

One question remaining is how we can avoid such over- interpretation of singular events. How can we make sure that the general trend is still intact?
Or to put it differently:
What are the respective demands on accident research?
A fundamental demand on accident research is the request or need of reliable data. Only such data will enable us to have a differentiated view on the road traffic accident situation.
In-Depth data can provide sound figures, but are limited to some specific investigation spots.

In order to have a more general view national road accident statistics are necessary. Within these police recorded data, all important circumstances of all national road accidents are reported. These data build the basis for traffic safety research on a general level and also play an important role in deriving road safety policy.

National data is however very limited with regard to the specification of personal damage. Casualties are only reported on the basis of three levels:

- Persons killed
  Being all persons who died within 30 days as a result of the accident
- Persons seriously injured
  Being all persons who were immediately taken to hospital for impatient treatment of at least 24 hours
- Persons slightly injured

Being all other injured persons

It is in particular the category of seriously injured road users which covers a wide range of injury severities, ranging from mild concussions to paraplegia.

The missing accuracy in the definition of personal injury has a detrimental effect on making cost efficient road safety policy which is not only focused on fatal accidents. This has also been recognized by the European commission. As a consequence - starting in 2015 - all EU member states are requested to provide more detailed data on the injury status of road casualties, with special regard to the group of seriously injured.

Accident researchers use the AIS classification to distinguish critically injured from moderately injured persons. This classification has been taken over by the expert group on European level. From the beginning of next year, each member state will therefore provide a number of surviving road casualties with AIS coding exceeding level 2.

This group of critically injured road users is also very important when it comes to cost benefit questions, related to the justification of some newly introduced regulation.

Studies done by BASt have shown that the socio economical cost associated with 3 critically injured road users is comparable to the cost associated with 1 fatality. Each critically injured road user represents a burden of about 400.000 €.

Based on these considerations it might be necessary to re-think about measures which did not show a reasonable cost benefit relation in the past, but might do so today.

These considerations will also change the view on acceptable injury risks. Whereas in the past, life threatening injuries have been focused it is now also multiple rip fractures, open fractures of the lower extremities and moderate CCI's [cranio-cerebral injuries] which will rightfully be placed on the red list of inacceptable injuries.

To make it clear, changing the view on seriously injured road users is one of the challenges which will substantially contribute to the optimization on future traffic safety.

But there are certainly many more challenges.

It is not only legislation, which wants to see the benefit of newly introduced regulations. It is also the automobile industry, which needs justification for the introduction of new safety systems.

Let me just touch on all current efforts to estimate the benefits of active safety systems, which - by the way - might just be the first step towards the safety assessment of automated driving. The dynamics of that development can hardly be pictured by conventional accident data, only.

To overcome this problem a couple of computer simulation based tools have been developed

- GIDAS Pre Crash Matrix
- VW Rate Effect
- BMW SAFER tool

just to mention a few of them.

In a different attempt, accident researchers have tried to combine national data from many countries – sometimes called the MUNDS approach - to get a better understanding of the real world performance of such innovative safety systems.

Both attempts are a **typical bottom-up procedure**, which have many advantages. They are pragmatic, can rapidly produce results and are budgetary friendly.

However – on a midterm perspective – questions need to be raised what data sources and tools will be necessary following a **Top-Down Approach.**

Conventional accident data will always be essential. But what will be required

- For the definition of unbiased testing scenarios
- For the characterization of False-Positive Scenarios
- For the identification of risk factors for automated driving and
- For the understanding of human machine interaction processes within normal driving as well as close to a critical event?

At this stage there are some promising candidates of data sources available, which could be

- EDR data, which shall be available in a broader extent in the near future.
- Data from ECU (Electronic Control Unit)
- Data from Traffic surveys and traffic counting including information on velocity profiles.
- Naturalistic Driving Studies and Field Operational Tests.

Especially these last two mentioned data sources are very promising approaches. They are required to obtain detailed data about driver behavior in real traffic situations.

This enables us to gain insight into normal as well as critical driver behavior and - as a result – it will enable us to deduct functions estimating the increase or decrease of accident risk associated with certain behaviors or vehicle functions.

In order to enable the introduction of highly automated driving functions in the future, such data is urgently needed.
And only by these means the safe interaction of drivers with advanced driving functions can be proved. We strongly recommend that joint efforts of the public as well as private sector should be taken in this direction, so that future far-reaching decisions can be taken with confidence founded on a sound data basis.

It is now the duty of the scientific community to ask the right questions, to develop a methodology and to merge all these data sources into a common framework for the assessment of future traffic safety innovations.

Certainly this is a complex task. And certainly this cannot be achieved solely by automobile industry or solely by governmental entities. To reach the goal a network of excellence is required and this is what makes conferences – like ESAR - so important. Conferences like ESAR shall be the focal point to start the discussion, to form groups of common interest and to drive the scientific progress.

In that respect I wish this 6th ESAR conference a big success, innovative thinking and fruitful discussions.
AND -
In order to already prepare the next step I would also like to take this opportunity to invite you to Bergisch Gladbach in November this year, where BASt will host the
"European interdisciplinary conference on ageing and safe mobility".
This will be a common initiative from

- The Forum of the European Road Safety Research Institutes (FERSI)
- The European Conference of Transport Research Institutes (ECTRI)
- The European Transport Research Alliance (ETRA)
- The European New Car Assessment Programme (Euro NCAP)
- The Forum of European National Highway Research Laboratories (FEHRL)
- The Human Centred Design for Information Society Technologies Network (HUMANIST)

The conference will focus on the road safety problems of elderly road users. The convention will aim at elaborating policy recommendations concerning implementation of available road safety evidence based on research results.

Participants are invited to take part in four sections:

- Human Factors
- Infrastructure
- Vehicles engineering
- Traffic Management Systems

The two-full-days conference will be held at the German Federal Highway Research Institute (BASt) in Bergisch Gladbach, Germany, on 27-28.11.2014.

Multinational In-Depth Accident Data: From Concept to Reality

J Bakker, D Ockel and R Schöneburg

Daimler AG, 71059 Sindelfingen, Germany

Abstract - While it is important to track trends in the number of road accidents in different countries using national statistics, there is a need for data with more detailed information, so called in-depth accident data. For this reason, several accident data projects emerged worldwide in recent years. However, also different data standards were established and so comparative analysis of international in-depth data has been very hard to conduct, so far. This is why the project iGLAD (Initiative for the Global Harmonization of Accident Data) was established and created the prerequisites for building up a standardized dataset out of the common denominator of different in-depth accident databases from Europe, USA and Asia. In the first phase, the project received funding from ACEA to compile an initial database. To accomplish this, a suitable data scheme has been defined, a pilot study has been conducted as proof of concept and the recoding of the first common data base has been initiated. Also, to prepare the project for its self-supporting continuation in the next years, a business model has been developed. This paper reports the history and status of the project, the current challenges and the creation of a capable consortium to maintain the data. In mid-2014, the initial database containing 1550 cases from 10 different countries will be completed and a first detailed view on this data will be possible.

1. INTRODUCTION

Since its start in late 2011, the iGLAD project (initiative for the global harmonization of accident data) has come a long way. The goal of the project is to build up a database of so called in-depth accident data on an international level. While most of the countries worldwide provide basic national statistics about the number of road fatalities or injured persons on a very high and aggregated level, in-depth data provides details about single cases, their environment, participants, collisions, injuries and safety systems. So far, no data that can be compared between different countries worldwide or even is in the same data format has existed. The iGLAD project took this momentum and strives for a uniform and international in-depth accident database, which is build up from the bottom on the basis of already existing databases. This is accomplished by creating a well-defined and simple layer on top of all participating databases, which serves as a common denominator of them. A more detailed description of the technical aspects can be found in [1].This paper reports about the status of the project and the current organizational setup.

2. HISTORY

iGLAD was initiated by Daimler AG, ACEA and different research institutes and announced as a working group at the FIA Mobility Group in October 2010. Supported by FIA and ACEA, the goal of the group is to define a common standardized accident data set as an effective foundation for developing and measuring road safety policy endorsements and interventions. It shall also establish how this data set helps to achieve the goals of the “European Road Safety Action Programme” [2] and the „Decade of Action for Road Safety“ [3]. iGLAD was confirmed by the FIA Manufacturers Commission in March 2011.

After presenting the basic concepts of iGLAD to NHTSA/NCSA, especially the NASS group in April 2011 and at the VDA congress [4], the project kick-off meeting followed on 30 September 2011 at ACEA, also marking the beginning of common and cooperative tasks of FIA and ACEA within the iGLAD project. One such task is a project assigned by FIA to analyse the traffic safety data situation in low-income and emerging countries, complementing the efforts of ACEA which initially address in-depth projects in higher and middle-income countries.

The first iGLAD working group meeting in March 2012 comprised a more detailed discussion on the common data scheme and steps necessary for a standardized data set. The first preparatory steps were accomplished in 2012, a study has been conducted by FIA/CEESAR on the worldwide existing and available accident databases. Meanwhile, a common data scheme has been drafted and as a proof of concept, a pilot study has been conducted where each data supplier converts a small set of accidents into the current version of the common data scheme data. This should show the feasibility of the approach and give a small preview of the resulting data set that could be provided by the iGLAD project. The nine countries taking part in the pilot study were: USA, India, Germany, Sweden, France, Spain, Austria, Poland, and Italy.

By end of 2012, the basic project setup had been accomplished and first technical and organizational issues had been solved, so that the first project phase could be started. Target of phase 1 was to build an initial database with at least 100 cases per country. Phase 1 should be finished by mid of 2014. The next section gives more details about the work accomplished in phase 1 and the current status of the project.

3. STATUS

After preparatory work in 2012, phase 1 of the project started in 2013 having a first tangible dataset as a goal. This time, ten countries were ready to deliver data in the demanded extent and quality. Estimates of the recoding effort showed that substantial funding was needed to accomplish the data processing. Appropriate funding was applied for at ACEA and it was granted under the condition that the project would be able to run in a self-contained mode after the initial ACEA funding. So, an effective business model had to be developed enabling iGLAD to run in future project phases without the need for funding from third parties. A separate task force was formed to find a balanced solution where all different roles in the project with all possible combinations were considered. The resulting business model is detailed in section 4. In the course of the first project phase, the following goals were accomplished:

- Common Data Set has been defined as the minimal set of data to collect for each case
- Codebook has been written for the Common Data Set
- Consortium Agreement has been written
- Sampling procedure has been defined
- Recoding data into the initial database has been started

At the time of this writing, the recoding and merging process for the initial database is finished by 80%. Figure 1 shows the data providers and number of cases for each country that comprise this dataset. A total of 1550 cases have been achieved provided by the following organizations:
VUFO GmbH and BASt (Germany), Applus IDIADA Group (Spain and Czech Republic), Uni Firenze (Italy), Uni Adelaide (Australia), JP Research (India), NHTSA (USA), LAB (France), SAFER (Sweden), VSI at Graz University (Austria).
Further organizations that currently actively participate in the project are:
FIA, ACEA, Daimler (Germany), Renault (France), Volvo Cars (Sweden), CEESAR (France), BRSI (Belgium), KATRI (Korea), CDV (Czech Republic).

4. ORGANIZATIONAL ASPECTS

Bringing a large number of organizations together and building up a common and working project structure is quite a challenging task. This is especially true, when no external funding is available and the group should continue without the coordination by an umbrella organization. As iGLAD currently is in the transition process to reach this target, it is worthwhile to look more closely at how this will be achieved.

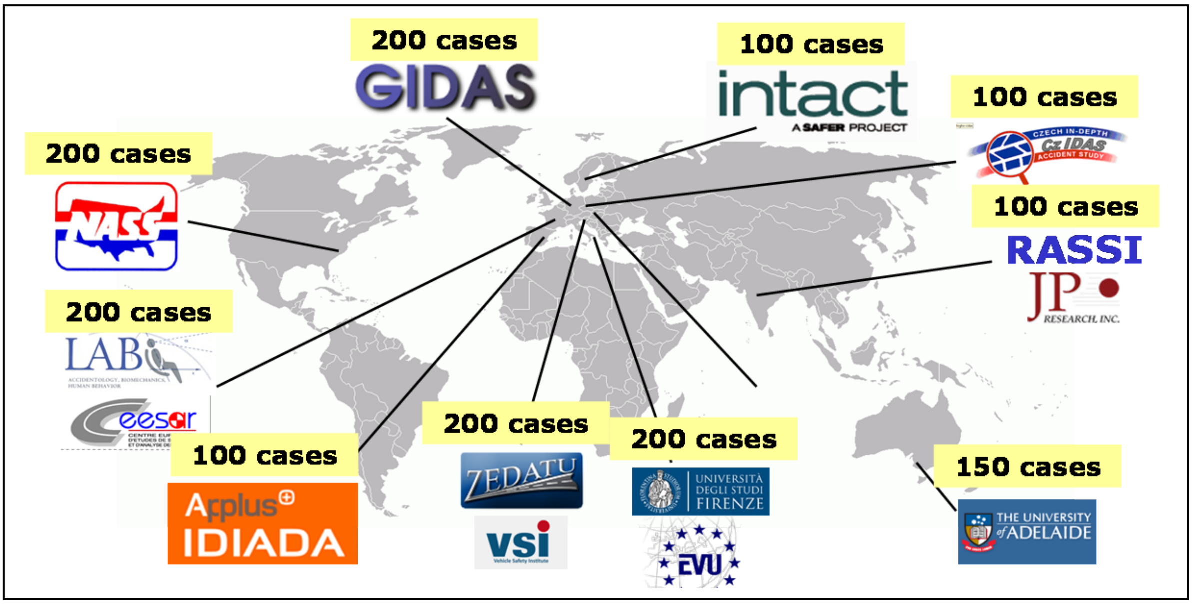

Figure 1 – Overview of countries and number of cases for initial database of phase 1 (2013).

Project structure

The transition from a funded project in phase 1 to a self-contained project in phase 2 needed some careful preparation. As there are many partners in the project with very different prerequisites, some interesting constellations appear. The biggest challenge was to find a structure that could deal with the flow of money and data within the project. For reasons of simplicity it was decided not to create a new legal entity, but to find a project partner that would be able to do the administrative work, which was hence named the Administrator. In detail, the tasks of the Administrator are:

- Creation of master account and debiting / crediting accounts within master account.
- Manage contracts with project partners. All partners (members and data providers) receive contracts on a yearly basis. The iGLAD Administrator serves as the contracting partner in all contracts. The iGLAD Administrator needs to track that all partners received contracts and manages the returned signed contracts.
- Yearly Invoicing to iGLAD members. Send out invoices to iGLAD members and keep track of the payment and incoming money.
- Conduct payment of iGLAD data providers. Payments of the data providers need to be conducted in time according to the amount of data send from the data providers. Maintain a balanced budget in the non-profit spirit. Propose membership fee adjustments when necessary.
- Record account management expenses and do housekeeping and quarterly balance reporting.
- Merge data samples from providers into iGLAD database. The data samples generated by the data providers need to be collected and added to the already available cases in the iGLAD database.
- Host a webspace to provide access to iGLAD database. A webspace needs to be provided by the iGLAD Administrator where the iGLAD database is stored. A password protected access for each iGLAD member to this webspace needs to be set up. Any changes in the list of iGLAD members have to be reflected in the access rights of the webspace.

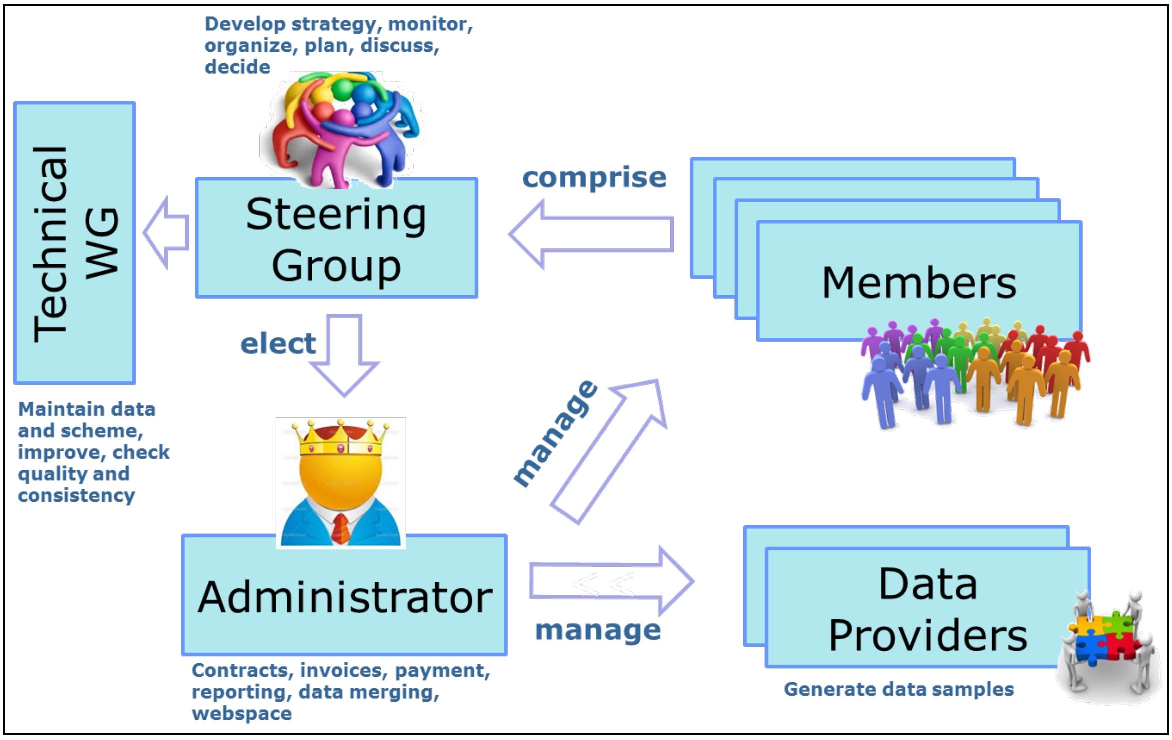

Figure 2 – Organizational structure of the project for phase 2 (2014+).

Of course, the whole project needs guidance by a central group which reflects the interests of the members and the evolvement of the project, which is the Steering Group of iGLAD. In detail, tasks of the Steering Group are:

- General issues, rights and duties
  - Constitution of the Steering Group members and renewal procedures
  - Legal procedure management
  - Main targets and role frame definition and enforcement
  - Reporting to the assembly
  - Public relationships, dissemination and special external agreements
- iGLAD membership regulation
  - New membership acceptance, procedure and control
  - Data usage regulation
  - Communications to the stakeholders
  - Penalties and dismiss members procedure
- Database management
  - Subcontracting procedures and control issues
  - Technical issues management
  - Quality control procedure
  - Data acquisition / sharing procedure
- Meetings
  - Meetings definition (Technical WG, Steering committee, Assembly)
  - Data and venue organization and communication
  - Minutes and ToDo list control
- General management
  - Administration and secretary issues
  - Dissemination

Additionally to the Administrator and the Steering Group, a separate group is needed to care about the technical details. This group reports to the Steering Group and is largely comprised by representatives of the data providers, but also consists of other members of iGLAD and is called the Technical Workgroup. In detail tasks of Technical Working Group are:

- Maintain common data scheme
- Maintain codebook
- Provide technical background
- Answer questions
- Provide expertise for coders
- Best practices, guidelines
- Provide common tools
- Methods of data exchange
- Integrity, plausibility, quality checks
- Sampling and extrapolation techniques

Figure 2 shows an overview of the organizational structure with the different groups and their relationships. The organization that acts as the Administrator has been elected by the current iGLAD Working Group out of six candidate organizations. The result of the election was that the Chalmers University in Sweden will take the role as the Administrator for the coming years. Also, the director of the VUFO GmbH in Dresden in Germany, Dr. Lars Hannawald, has been appointed as the head of the Technical Working Group. The formerly acting iGLAD Working Group currently serves as the intermediate Steering Group as there are no official members, yet. So, the head of the Steering Group is still to be determined. However, the basic structure is already in place and phase 2 can be started right away, which basically involves acquisition of the members and contractual setup in the first place.

The whole project structure along with their different parties, their tasks, rights and duties are defined in the iGLAD Consortium Agreement (CA) which lays the foundation for the consortium contracts, both in phase 1 and phase 2. The CA has been developed by using a RASIC matrix, where all roles and their relations in terms of "Responsible, Accountable, Support, Informed, and Consulted" are defined based on a list of all tasks of each role. This RASIC matrix is a tool to ensure that all aspects have been handled and the CA completely covers the rights and duties of each party. Figure 3 shows an excerpt of this RASIC matrix.

Activity	Administrator	Member	Data Provider
Consortium agreement / contractual issues	A	R	I
Controlling of rights and duties	R	I	I
Renewal of Steering Committee leadership	A	R	I
Handle member issues	R	I	I
General procedure	R	I	A
Database maintenance	A	I	R
Data schema changes and updates	I	R	I
Accident cases approval, quality check	A	I	R
Data merging, download	R	I	I
Providing download infrastructure / webpage	R	S	S
Data quality specification and check	R	C	C
Data quality assurance	C	C	R
Data upload	I	I	R
Data recoding / creating a data generator	I	I	R
Data feedback to iGLAD partners (?)	I/A	I	R
Sale of data, money transfer	A	I	R
Regulation of data access	R	I	I
Determine and control data usage conditions	A	R	I

Figure 3 – Excerpt of RASIC matrix for relationships between project roles for phase 2 (2014+).

Business model

There have been extensive discussions in the project on how an appropriate financial model that would reflect and balance the interests of all parties for the self-contained phase 2 of the iGLAD project would look like. One initial thought, and also a very simple model for sharing data between loosely coupled research groups, is to just share the data without involving any financial resources. However, reality is a bit more complex and there are partners in the project that only want to provide data or just use the data for analysis. Moreover, there are big differences in the size of the partners. While one data provider has more financial resources and the minimum sample size of 100 cases is an easy task to achieve, other partners reach their limit and are glad to just reach this barrier. Additionally, a big project partner like GIDAS [5] that involves many different organizations also means that more organizations can benefit from the iGLAD data set. This leads to a mismatch between the contribution and the benefit between small and large project partners. The solution is to properly separate each role and its interests and balance all interests on a financial basis. However, this doesn't mean that iGLAD will turn into a profit generating model in phase 2, but strictly remains a project that generates data for non-profit and research purposes.

Finally, when having a closer look at different opportunities and views from different project partners, the task force that should build up a viable business model came to a host of different setup scenarios and interests. The first step was to find out the different roles in the project. It turned out that there are exactly three different roles: Members, Data Providers, and Data Owners (see figure 4). Each party of the project can be assigned one or more of these roles. Even all three roles are possible for a single party. Members are parties that are interested in using the data, Data Providers deliver the data for a specific country to the project and Data Owners have to grant access to the delivered data.

In a second step, relations between the different roles were defined along with the flow of data and financial resources. In order to compensate for the different sizes of projects partners, two options were introduced for the Data Owners. Usually, the owner of the data is compensated with a certain amount of money for providing a sample of his data to the iGLAD project. For big organizations that provide data to the iGLAD project there is also the option to offer a reduced iGLAD membership fee to all organizations that are covered under the umbrella of this specific Data Owner, but each organization has to become a Member of iGLAD to have access to the iGLAD database.

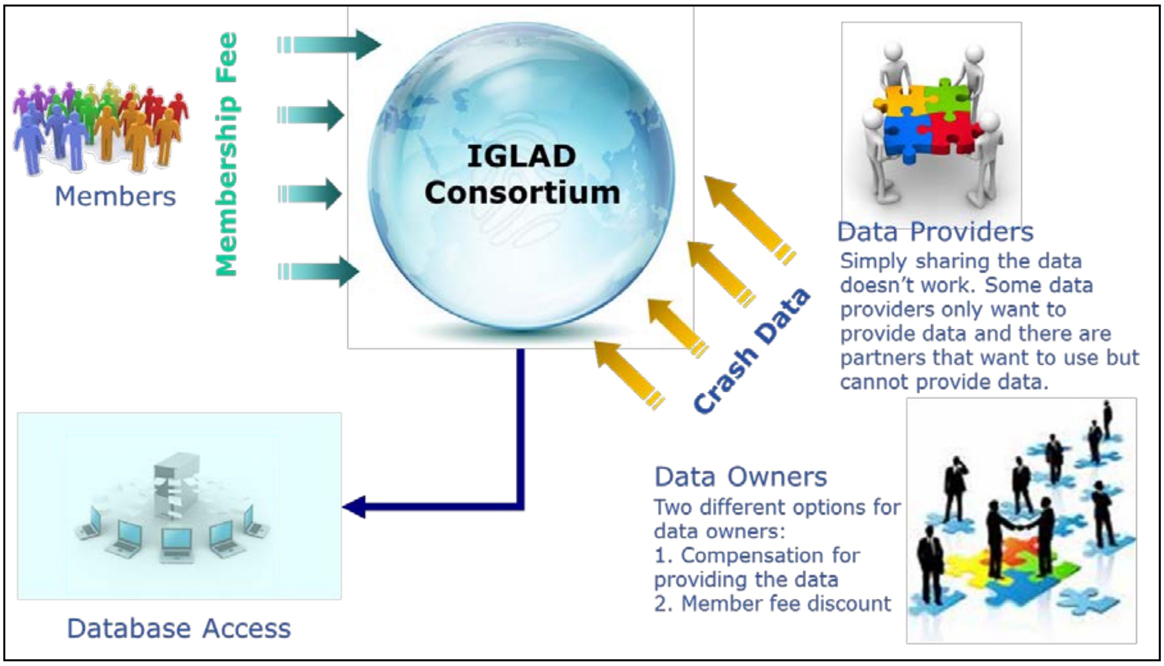

Figure 4 – The business model balances interests in the project for phase 2 (2014+).

As a means to verify that the proposed business model would also work in reality and would lead to a balanced level of funding, a simulation has been conducted based on letters of intent for data providers and potential members. This simulation provided enough confidence for the current model to come into effect.

5. SUMMARY, NEXT STEPS, LONG TERM GOALS

The approach taken by iGLAD is very pragmatic: See what is already there and build on top of it [4]. Also, the results are kept small and simple. iGLAD strives to find an optimum between unifying a limited number of parameters and maintaining realistic targets and effectiveness. To achieve this, the different interests of the supporting parties need to be carefully balanced. Therefore a well suited business model has been developed, to enable the project to continue beyond the starting phase which was funded by ACEA. Also, an appropriate project structure is currently established to organize the different tasks within the project. The result should be a well-balanced data set, where each party provides and receives comparable value. As an additional benefit for the data suppliers, the common data subset might spawn interest for further analyses (or contracted analyses) of their detailed data, i.e. the data available beyond that provided by the common subset.

Nevertheless, despite its target on simplicity, it is important that the data creates a useful basis for typical accident data analysis questions. To accomplish this, the working group needs to prepare relevant use cases of the data for demonstration purposes. After finishing the first data set in mid of 2014, a detailed analysis conducted by different iGLAD members will be started. This hopefully generates enough interest in the data and attracts more members to ensure the continuation of the project. While the next step in the project is to establish the structure for the second project phase, iGLAD's long term goal is to establish a sustainable database of international in-depth data for research purpose and improvement of global road safety.

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Establishment of Korean KIDAS under the limited accident related data

Y. Youn[*], S. Lee[**], S. Kim[***], J. Lee[***], K. Lee[****], S. Kim[*****]

* Korea University of Technology & Education, School of Mechatronics Engineering, Cheonan, Korea
* Korea University of Technology & Education, Graduate School, Cheonan, Korea
*** Korea Automotive Testing & Research Institute, Hwaseong, Korea
**** Yonsei University, School of Medicine, Wonjoo, Korea
***** Kunkook University, School of Medicine, Chungjoo, Korea

Abstract
Although, the annual traffic accident statistics published by the national police is available in public, but, the detailed traffic accident data has not been released in Korea. Recently, Ministry of Land, Infrastructure and Transport recognized the important of in-depth accident data to enhance road traffic safety and initiates research project for establishing collection of the detailed accident data. The main objective of the project is feasibility study for the establishing KIDAS. Under the project, three university hospitals which have located mid-size cities have been selected to collect accident data. Annually, approximately more than 500 cases of accidents have been collected from the in patients interview and diagnosis. Unlike GIDAS, on-site investigation can't be performed currently in Korea police policy. The only available data is patient medical records, patient description of accident circumstance and damaged vehicle at the garage. Occasionally the police provide the accident investigation reports which the information is very brief in terms of causation of accident as well as vehicle safety. In this study, as first attempt, the concept of KIDAS is to adopt format of iGLAD for harmonization. Since the current collected accident information is extremely limited compared with GIDAS, the other sources of data and calculations such as KNCAP vehicle data, pc-crash simulations, vehicle registration information, insurance company data and photomodeler are utilized to fill the blank part of iGLAD template. Results from the constructed KIDAS_iGLAD, the limited cases of assessment of active safety device such as AEBS, ESC, and LDWS will be evaluated.

NOTATION

E= the amount of absorbed energy by a car
L= width of crush
C= represents the crush depth
A, B = Coefficients
θ= force angle from perpendicular

INTRODUCTION

Economical point of view, Korea is now top 10 countries globally including of 7th ranking in export, 10th in trade volume, and 5th vehicle production volume. However, according to global statistics in road safety field, Korea is ranked in 29th of 32 OECD countries in 2011. The number of deaths per 100,000 populations was 10.5 (OECD average 6.8) persons and the number of deaths per 10,000 vehicles was 2.4 (OECD average 1.2) persons.

In road safety, the first step in the process is identifying significant safety enhancement areas and the mechanisms of accidents and/or injuries that govern the problem. Ministry of Land, Infrastructure and Transport of Korea also prescribed as a law for the establishment of the every 5 years national strategy plan to reduce traffic accident. In September 2011, the Ministry (MLIT) announced 'The 7th National Transport Safety Plan' for the period (2012-2016). The plan includes major safety issues for road, railway, aviation and marine transport. In the field of road safety, the plan aims at reducing fatalities to less than 3 000 by 2016 (almost a 40% reduction in comparison to 2010) in order to be ranked in the middle among OECD member countries as shown in Table 1.

Two main targets have been set for 2016:
1) Reducing by 40% the number of fatalities by 2016 in comparison to 2010 level.
2) Reducing the risk (calculated as the number of deaths / 10 000 vehicles) to 0.5, in order to reach the average level of OECD countries.

Table 1. National road fatality reduction target for 2016 and 2020

Category	2010	2016	2020
Annual traffic crash death	5 505	3000	1 200
Number of death per 10 000 vehicles	2.6	1.3	0.5

To meet the national target, the most effective tools or national resources for enhancing vehicle safety should be enhanced and expanded as shown in Table 2

Table 2. Strategies and main measures of national road safety plan

Strategies	Main Measures
User behaviour improvement	• Reinforce school road children traffic safety • Grope for change to children based traffic safety training • Reinforce aged drivers traffic safety measures • Reinforce punishment of important regulations violator such as drink and drive. • Advancement of automobile insurance system • Introduce operation hour limit for business use vehicle • Diversify traffic safety public relations and training
Build safer infrastructure	• Secure safe and fresh passing area • Expand safety aimed traffic safety facilities • Promote traffic safety improvement business of local unit • Prepare bicycle traffic safety measures • Revitalization of traffic safety information sharing
Operate smarter modes	• Expand automobile high technology safety device dissemination • Expand business use automobiles safety device dissemination
Reinforce safety management system	• Speed management based on human system change • Advancement of traffic accident cause investigation with high technology
Advanced emergency response system	• Build synthetic post disaster response system • Build weather information providing system

MLIT is the national government body responsible for road traffic safety planning, vehicle safety regulations, New Car Assessment Program of Korea (KNCAP) and management of road construction as well as built roadside infrastructures. In order to maximized road safety, it must be determined what types or patterns of accident and sever casualties were most frequently occurred in the real roads based on the statistical analysis of traffic accidents.

Figure 1. Trends towards national target

Meanwhile, in Korea, crash data are collected by the National Police Agency. There are two set of accident data available in Korea. One directly reported and collected by local police which injury involved accidents and others is collected through the insurance companies and traffic service associations. As a definition, Fatality data refer to deaths within 30 days. Injury crashes are defined as crashes resulting in at least one injured or killed person. A person seriously injured is defined as a person requiring medical treatment for more than 3 weeks. However, police is only one authority for accident investigations for reported accident in Korea. No other body can't access or on-scene investigation without police permission. Like other countries, their primary role for accident investigation is found out who is 1st responsible for the accident or violates the traffic law. Nevertheless, the written macroscopic level of accident statistical data is available for pubic annually, it is not suitable for addressing traffic safety enhancement to analyze the real road vehicle safety problems.

VEHICEL SAFETY ENHANCEMENTS

Historically governments and research organizations have used the traditional statistical approach to assess benefits of safety program such as NCAP or safety device using in-depth crash data which normally allows a more detailed level of analysis. In Korea, public available accident data is only published police report, not allowed direct accessing the detailed raw database. Current Korean in-depth accident database as research purpose has a limited number of cases and is still in the early stages. In this study, as an alternative, the improvement of vehicle safety in terms of KNCAP rating was compared the tested vehicles in chronological order.

For frontal crash tests, the average combined serious injury risk probability (AIS 4 +) for the first 3 years tested vehicle (1999-2001) was 21.6%. Safety performances have been significantly improved, in the last three years (2011-2013), the average P_{comb} value was decreased to 15.1%. Results from side crash test analysis, the probability of serious injury (AIS 3 +) was 11.3% in 2003. In 2013, the value was dramatically dropped to 2.0% as shown in Figure 2. Side pole impact case, potential serious injuries (AIS 3 +) is 95.6% in 2009 and also dropped to 8.9% in 2013 (see Figure 3). Side pole crash test was added in KNCAP protocol as an optional test which manufacture's choice to get maximum additional 2 points from this extra test. Within four years, even though side pole test was initiated as an optional test, but recently most of vehicles are equipped with side curtain airbag as standard option. In addition, it was clearly proven that side curtain airbag is most effective safety device to protect occupants from the side pole collision type accidents [1, 2, 3].

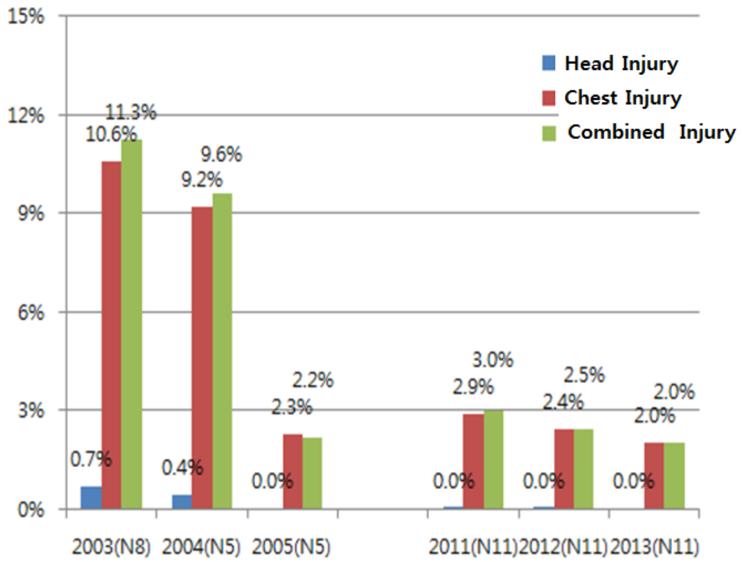


Figure 2. Improvement of side crash safety

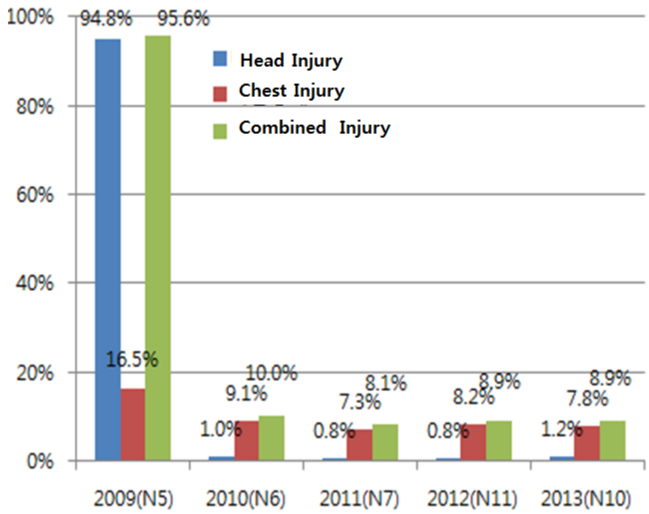


Figure 3. Improvement of side pole crash safety

Pedestrian safety in 2013 compared to 2008 was improved nearly twice times (see Figure 4). But still pedestrian accidents and higher fatality is big issues which given the plenty of room for improvements in KNCAP.

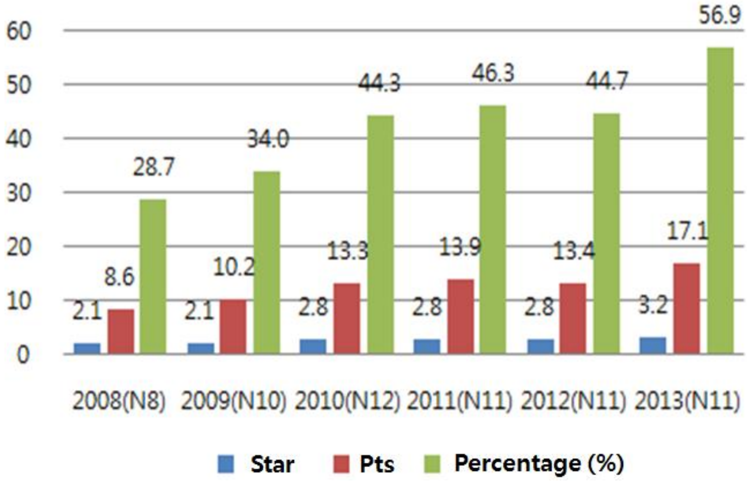
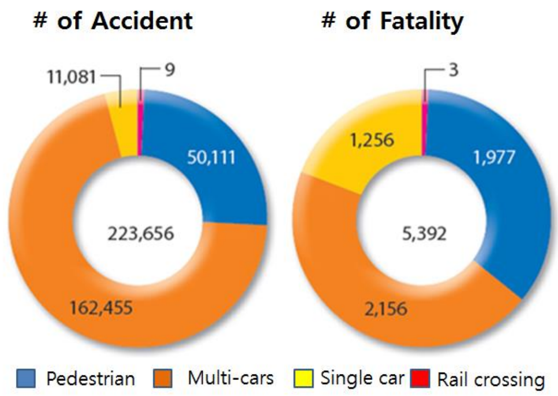


Figure 4. Improvement of pedestrian safety

MACROSCOPIC STATISTICS OF TRAFFIC ACCIDENTS

From police report which counted only injury involved road traffic accident in 2012, the total number of accident was 223,656 cases, 5,392 deaths (within 30 days), and 344,565 injured persons were reported. As shown in Figure 5, fatalities involved the accident patterns can be classified by 1,997 deaths from car-to-pedestrian accidents (37.0%), 2,156 deaths from car-to-car accidents (40.0%) and 1,256 deaths from single vehicle involved accidents (23.3%), and rail crossing type accidents involved 3 deaths in 2012 [4]

According to classification by types of road user, fatality can be categorized with 2,027 (37.6%) deaths from pedestrians, 2,090 (38.8%) deaths from vehicle occupants, 908 (16.8%) deaths from motorcyclists, 286 (5.3%) from bicyclists, and 81 (1.5%) deaths from other types of road users as shown in Figure 6. The passenger vehicle involved 49.7% of all fatal accidents while trucks were share of 22.8% and 12.1% from the motorcycles.



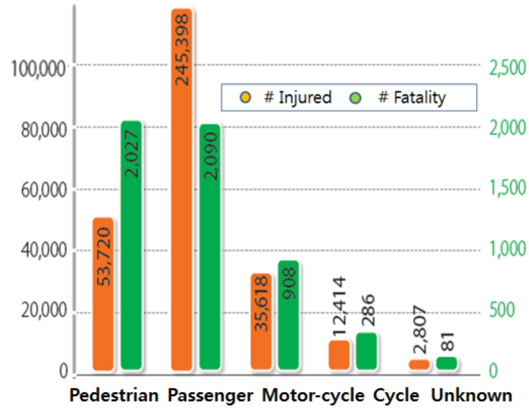


Figure 5. 2012 Fatalities by accident types

Figure 6. 2012 Casualties by road users

According to the police statistical data, the head-on collision was shown the most fatal severity. The fatality rate was 4.6 deaths out of 100 accident cases while side collision showed 1.1 deaths ratio, rear collision while driving was 1.3 deaths ratio, rear collision while parking was 1.1 deaths ratio as shown in Figure 7. It was also noticed that ration of female driver involved accident and fatality of female driver was continuously increased. In 2012, 16.6% of traffic accidents were caused by female driver. The female driver's fatality rate has been reached up to 9.3% which meant 9.3 deaths of female driver out of 100 cases of accidents.

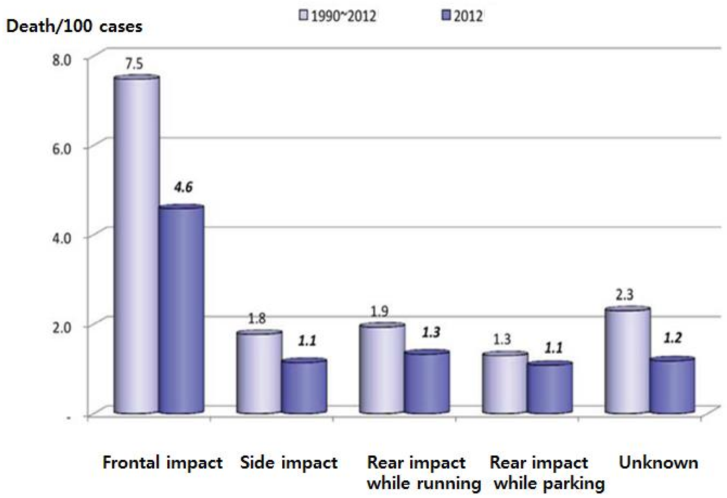


Figure 7. Fatal severity ration in car-to-car accident in 2012

INITIATION OF KIDAS BASED ON iGLAD

The issues of current traffic accident investigation and data collection from polices in Korea were very limited access for an individual accident event. Also, the lacks of automotive related information which police is not much concerned, are very difficult to analyze the accident involved vehicle's safety problems. The total 97 variables [5] are normally collected according to the specification of police report format, but, only 27 variables are accident related items. The detailed accident types, collision types, vehicle specifications, injury severity of occupants, detailed restraints system and seated positions were missed from the report.

As part of Korea Advanced Safety Vehicle (KASV: 2009-2017) project, the pilot study of KIDAS(Korean In-Depth Accident Study) has been initiated in 2012. The research organizations are consisted KATRI, KoreaTech and 3 Medical schools to collect accident data as well as establishment of KIDAS structures. These three medical schools are located within 150 km boundaries of Seoul metro area as shown Figure 8.

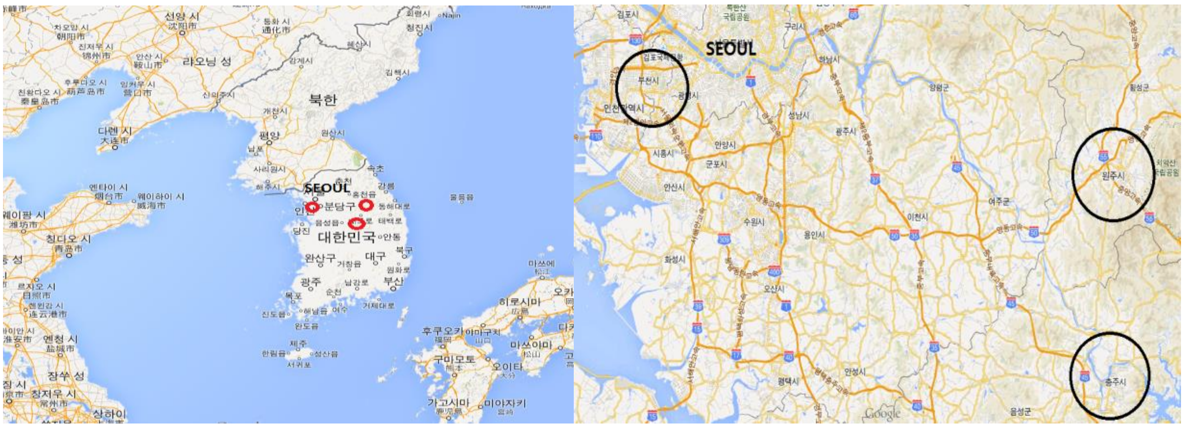


Figure 8. Locations of 3 hospitals for accident data collection

Unlike other DBs, on-site investigation is not allowed, all collected accident data were related to in-patient of 3 medical school's hospitals. Once injury involved accidents occurs, the occupants may in-hospitalized these emergency centers. After medical treatments, the research team can search for police station for more information but, unfortunately not always successful achieving accident data from police due to the privacy protection restrictions. After collecting police's accident report or verbal information related the accident with inspection of crashed vehicle, even though the total amount of collected data is limited, can be constructed the each individual accident database.

In globally, there are numerous numbers of in-depth accident database are exist. For instance, GIDAS is one of most sophisticated in-depth databases in the world with 30 different categories which required about 2,500 input variables [6, 7]. Also, recently, "iGLAD" (the Initiative for the Global Harmonization of Accident Data) has been initiated by FIA's Mobility Group and ACEA in Europe [8]. As objectives, iGLAD considers all corresponding regional standardisation efforts and strives to ensure continuous exchange of information to avoid individual, non-harmonised approaches, redundant activities and duplication of work. Therefore, as the first step, the research team decides to adopt iGLAD format as KIDAS structure as a Korea standards in-depth accident study. It will be continuously modified to accommodate regional traffic environment effects, but keeps the fundamental structures of iGLAD.

ESTIMATION OF ENERGY EQUIVALENT SPEED

In short term, the most driving force of establishment of KIDAS in this ASV project, is required cost-benefit analysis for each individual active safety device. To estimate real benefit of road safety in terms of reducing numbers of accident as well as injury levels, in-depth accident database is essential to set up the specific accident scenarios of advanced vehicles.

One of the most frequent missing data is impact speed or delta V of the accident. Since on-site investigation was not allowed, the trace of accident can't be collected as it was. As an alternative method, photo-modeling technique was adopted to overcome limit access or deformation measurement of crashed vehicles with photographic scale measurements as shown in Figure 9. EES can be determined in both deformation and stiffness of vehicle structures. In the event of vehicle crash, the absorbed impact energy is depended on the stiffness of vehicle as the following equations [9, 10, 11].

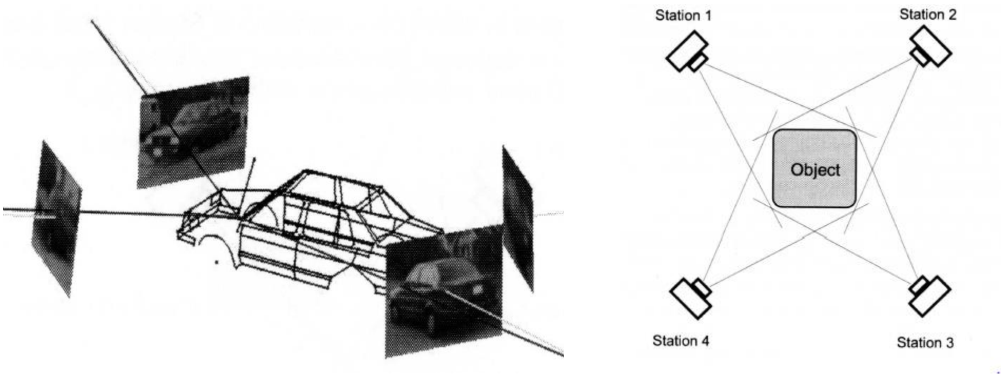


Figure 9. Application of photographic technique (from PhotoModeler Manual)

$$EES_{of\ the\ vehicle} = \sqrt{\frac{2E}{m}} \tag{1}$$

$$E = L(AC + \frac{BC^2}{2} + G)(1 + \tan^2\theta) \tag{2}$$

Where E= the amount of absorbed energy by a car
L= width of crush
C= represents the crush depth
A,B = Coefficients
θ= force angle from perpendicular

In this study, PhotoModeler S/W was used to measure the crashed vehicle deformation as shown in n Figure 10.

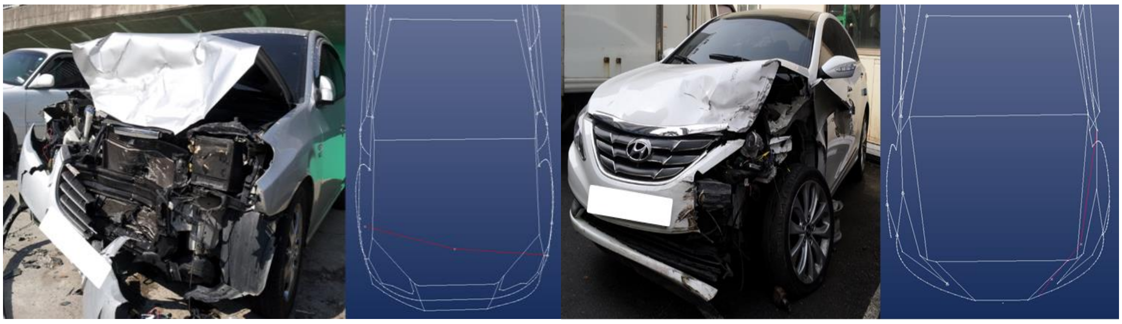


Figure 9. Vehicle deformations calculation using PhotoModeler

DISCUSSION AND FUTURE WORKS

The main purpose of establishing KIDAS is needed a detailed accident data for national level future planning strategic road traffic safety in terms of vehicle, injury, and road safety. As stated in the previous chapter, from the AVS project in Korea, KIDAS (Korea In-Depth Accident Study) program was initiated as a pilot steps, however, the final goals will be set-up a permanent institution for a detailed accident data. Current situation of establishment of KIDAS in Korea needs overcomes of a lot of obstacles. 1) One of main problems is accessing on-site investigation and sharing police investigation reports which required mutual agreement between MLIT and National Police department. 2) collects accident data without criticizing personal information protection policy 3) needs accident investigation technical experts.

As a role model, GIDAS is one of best database. But, it will be long term goal to adopt GIDAS variable format. In current situation, GIDAS, the most sophisticated in-depth databases in the world with 30 different categories which required about 2,500 input variables can't be achieved in a short period of time. Therefore, as the first step, the research team decides to adopt iGLAD format as KIDAS structure as a Korea standards in-depth accident study. It will be continuously modified to accommodate regional traffic environment effects, and expanded to GIDAS approaches.

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Tool for the determination of influence parameters on the accident emergence during the pre-crash phase as an enhancement of the Accident Causation Analysis System ACAS

Pund, B.[1], Jänsch, M.[2], Otte, D.[2]
[1] *TÜV Technische Überwachung Hessen GmbH, Life Service*
[2] *Accident Research Unit, Hannover Medical School*

Introduction

The method of causation analysis applied under the German accident survey GIDAS, which is based on Accident Causation Analysis System (ACAS) focuses on an on-scene data collection of predominantly directly event-related causation factors which were crucial in the accident emergence as situational resulting events and influences. The paradigm underlying this method refers to the findings of the psychological traffic accident research that most causally relevant features of the system components human, infrastructure and vehicle technology are found directly in the situation shortly before the accident.

This justifies the survey method which is conducted directly at the accident (on-scene), shortly after the accident occurrence (in-time) with the detection of human-related causes (in-depth). Human aspects of the situation analysis that interact and influence the risk situations shortly before the collision are reported as errors, lapses, mistakes and failures in ACAS in specific categories and sub-categories. Thus methodically ACAS is designed primarily for the collection of accident features on the level of operational action, which certainly leads to valid findings and behavioral causes of accidents. The enhancement by means of Moderating Conditions concerns the pre-crash phase in different levels: strategical, tactical and operational.

Accident Moderating Conditions as influence factors

Overlasting influence factors which are temporally active before the accident and which themselves are not a direct cause of the accident, however, which play an indirect, rather moderating role in the accident occurrence, are only marginally detected by ACAS, which focuses on the situational factors within the conflict phase. Examples are the existence of perceptual debilitating symptoms due to distraction or the influence of human affective situations such as sensation of stress. Such influences have existed for some time before the accident and do not represent a necessary condition for the occurrence of the accident, but can in the immediate conflict situation play a crucial role, as they affect the availability of human functions such as attention attitude.

Even technical or infrastructural deficiencies or organizational errors are often present in time far before the accident, but in the immediate conflict phase result in an additional destabilization of the system with the result of an increase in the probability of the occurrence of the accident, where they come to effect only in the interaction with situational features.

This rather invariant influences are present before the accident as moderating conditions, while the causation factors described in ACAS appear more situational and with higher variability. This applies especially to human behavior, where antecedent conditions are not fully covered with the previous methodology.
Therefore, an extended approach to the accident causation analysis was developed that not only takes into account the "final state" with the situational characteristics, but also records enduring characteristics which were active in time far before the accident. Although isolated these characteristics are not considered causative, they have however influenced the accident occurrence in a reinforcing manner. Such moderating conditions at the level of human behavior are for example attitudinal and motivation-related personal characteristics such as adaptability, risk tolerance and aggression. Another class of in time preceding or strategic planning errors that are only effective at the time of the accident, refer to the human-machine interface (for example, incorrect attachment of a trailer which shows effect only in the conflict situation shortly before the accident).
This study deals with the presentation of such moderating conditions and displays the possibilities and limitations to make these factors accessible for an accident analysis as an addition to the data from ACAS.

Development of Accident Moderating Conditions (AMOC)

Two classes of models with different backgrounds and purposes have become useful in distinguishing between different driving tasks and respective driver information processing activities. One class is in the tradition of the attempt to model driver behavior as a hierarchical task (JOHANNSEN 1976, JANSSEN 1979), the other has been developed by RASMUSSEN (1983) in the context of supervisory control tasks. Several authors have attempted to combine these models (e.g. PARKES 1989, HALE et al 1990).

The general plans from the strategic level have to be transformed into controlled patterns of action. Behavior at this manoeuvring level is mainly rule-based, i.e. it follows learned “if-then” rules. The driver e.g. decides to overtake and retrieves the necessary information about the actions for that manoeuvre from long-term memory. Finally, on the control level of driving, strongly habitualized action patterns dominate the behavior. Actions on that level are quick, efficient and can be taken without great subjective effort. They are called skills and they don’t afford conscious attentional control by the driver. For an experienced driver, examples of skills are using the steering wheel, clutch, brake etc.

Level	Strategical	Tactical	Operational
Human related organizational conditions	e.g. bad driving education e.g. driving in darkness despite reduced contrast eyesight	e.g. poor management concerning drinking and driving e.g. false attachment of trailer to vehicle e.g. driving despite lack of sleep	e.g. dysfunctional DAS (ACAS)
Human functional conditions	e.g. high potential of aggression e.g. restricted driving ability by dementia e.g. general non-acceptance of traffic rules	e.g. aggressive driving due to irritation e.g. risky driving to impress others e.g. deliberate red light violation	e.g. distraction (ACAS)

Figure 1: Accident moderating conditions concerning the 3 levels of driving tasks (examples).

The enhancement of the accident causation analysis concerns the consideration of factors that are effective during the pre-crash phase. The data collected by ACAS provide more immediate / direct factors from the phase of the traffic conflict, whereas the enhanced approach considers those features which precede temporally and represent a more general factor in the accident development. These factors relate to the strategic or tactical level, whereas the level of direct operations are covered by the ACAS parameters during the conflict phase (see figure 1). The question is, which over lasting factors, mostly human, contribute to the emergence of an accident and make the accident occurrence more likely. Even though these unspecific conditions cannot be regarded as direct accident causes they can be effective as additional risk factors, which show their influence in an instable and ambiguous conflict situation. They can be described as hidden immanent hazards, situated mostly on the strategic level. These indirect antecedent features are effective as accident moderating conditions (AMOC) at the accident origin and primarily represent enduring characteristics in the human system component. These are mostly safety related attitudes and inappropriate personality factors such as impulsivity, general hostility towards others, bad self-control and positive attitude towards excessive speeding. Well known are empiric findings that indicate a high correlation between traffic accidents and biographical data of the person that is involved in an accident (e.g. the number of previous violations of traffic rules and the number of previous accidents). Moreover international findings emphasize the influence of certain personal disorders on hazardous behavior in traffic and on high risk of accident emergence, like the borderline disorder and the dissocial disorder (Rößger et al, 2001; Schade, 2005; Junger et al, 2001; Dahlen et al., 2005; Banse, 2013; Sarma et al, 2013).

As "sleepers in the background" such moderating conditions show their effects only in interaction with situational conditions and will only be effective in traffic conflict situations certain driving tasks need to be accomplished and/or instable vehicle dynamics. Those "sleepers" also affect the availability or provision of necessary human functions, by suppressing e.g. orientation reactions or avoidance reactions.

Examples for causation factors	Methods of investigation
Inclination to aggression Arousal of anger / irritation Hostility towards other road users	➢ Observed aggressive action (by witnesses) ➢ Self reported aggressive behaviour (in interview) ➢ Aggressive interaction during interview ➢ Findings by retrospective questionnaire
Hypoglycemia (diabetes)	➢ Self reported prodroms and symptoms ➢ (Self) reported diagnosis ➢ Findings by retrospective questionnaire ➢ Interview of doctors ➢ Access to clinical reports

Figure 2: Examples for accident moderating conditions and possibilities of identification in the scope of accident investigation.

With the help of two examples from the human system component (figure 2) possible data sources and the possibilities of identifying hidden immanent hazards in the field of personality and traffic-relevant diseases are displayed (inclination to aggression and diabetes). Although accident moderating conditions are more difficult to identify than ACAS data, indicators for the presence of such indirect effective causation factors that can be identified in the scope of in-depth accident data collection.

If we take into account such clinical, psychological and organizational data of the "history of an accident" we come much closer to the idea of an in-depth analysis in real-world accident scenarios.

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EVOLUTION OF THE FIGURES OF CASUALTIES FOR BUS/COACH OCCUPANTS WITH CORRESPONDING RISK INDICATORS COMPARED TO THOSE FOR OCCUPANTS OF CARS AND GOODS VEHICLES

A. Berg

DEKRA Automobil GmbH, Handwerkstraße 15, D-70565 Stuttgart

Abstract -The paper gives an overview of the recent (mostly 2012) figures of killed bus/coach occupants (drivers and passengers) in 27 Member States of the European Union as reported by CARE. The Evolution of the figures of bus/coach occupants killed in road accidents urban, rural without motorway and on motorways from 1991 to 2010 in 15 Member States of the EU supplements this information.

More detailed are the figures reported for Germany by the Federal Statistics. The paper displays long-term evaluations (1957 to 2012) for killed, seriously and slightly injured occupants in all kinds of buses/coaches. Mid-term evaluations (1995 to 2012) of the figures of fatalities and casualties are displayed for different busses according to their identification of road using as coaches, urban buses, school buses, trolley buses and “other buses”.

To be able to compare the evolutions of the safety of vehicle occupants it is customary to use different risk indicators. Calculations and illustrations for three often used indicators with their development over time are given: fatalities, seriously injured and slightly injured per 100,000 vehicles registered, per 1 billion (10^9) vehicle-kilometres travelled and per 1 billion (10^9) person-kilometres. These indicators are shown for occupants of cars, goods vehicles and buses/coaches.

For the period from 1957 until 2012 it is obvious, that for all three vehicle categories analysed there was a clear long-term trend towards more occupant safety in terms of casualties per vehicles registered and per vehicle mileage. This was most significant for car occupants but it can be seen for bus/coach occupants and goods-vehicle occupants as well.

Figures of killed occupants and of casualties related to person-kilometres are calculated and displayed for the shorter period 1995 to 2012. Here it becomes obvious that the bus/coach is still the safest mode of transport for the occupants of road vehicles. Graphs for the casualty risk indices still show significantly higher risks for car occupants despite the corresponding curve moved sustainable downwards. It is remarkable, that the risks of being killed or injured for the occupants of urban buses is growing whereas the corresponding risk for the occupants of coaches in line traffic tends downwards.

The article ends with a short comparison and discussion of the risk indicators which are actually published for the occupants (driver and passengers) of cars and the passengers of buses/coaches, railroads, trams and airplanes. The interpretation of such information depends on the perception and it seems that for a complete view not only one indicator should be used and the evolutions of the indicator values during longer periods (as displayed with examples in the paper) should also be taken into account.

KEY WORDS

Bus, Coach, Statistics, Accident, Fatalities, Casualties, Risk Indices

INTRODUCTION

Since decades to travel in buses and coaches is one of the safest modes of passenger traffic. Furthermore bus travels are most friendly to the environment. For urban and short-trip transport as well, the bus is an important alternative to travel by car. For long-distance-line travelling (remote-bus traffic) new possibilities are licensed by law in Germany since January 1st, 2013 and opened new possibilities for the customers. This gives good reason for updated overviews on the accident figures and risk indicators for occupants of buses/coaches (vehicle categories M_2, M_3) and compare them for example to those for occupants of cars (M_1 vehicles as an alternative to travel on roads) and of goods vehicles (categories N_1, N_2, N_3) which are in general more heavier road vehicles than cars.

BUS/COACH OCCUPANT FATALITIES IN THE EUROPEAN UNION

The European database CARE (Community database on road Accidents Resulting in death or injury) reports the current total number of traffic fatalities for the year 2012 with last refresh date on March 17, 2014 as 28,459 (all road users) [1].

The data come from 27 member states of the EU (EU 28 without Lietuva which is not reporting to CARE) and they are continuously maintained and updated by the latest available national statistics. On the stated day there was a total of 92 killed occupants of buses/coaches of which 20 were drivers (22%) and 72 passengers (78%), **Table 1**.

In CARE, road fatalities are defined as road users who die due to the consequences of an accident immediately or within 30 days. Buses/coaches (buses, minibuses, coaches and trolleys) are defined as passenger-carrying vehicles, having more than 16 seats for passengers. Buses are most commonly used for urban public transport, coaches for interurban movements and touristic trips. To differentiate from other bus types, a coach has a luggage hold separate from the passenger cabin. Relative to the total of 28,459 fatalities (all road users) in the 27 member states, 92 killed bus/coach passengers represent a proportion of only 0.3%.

Table 1: Current figures of bus/coach drives and passengers killed per year in road accidents in 27 member states of the EU (Source: CARE [1] last refresh date: March 17, 2014)

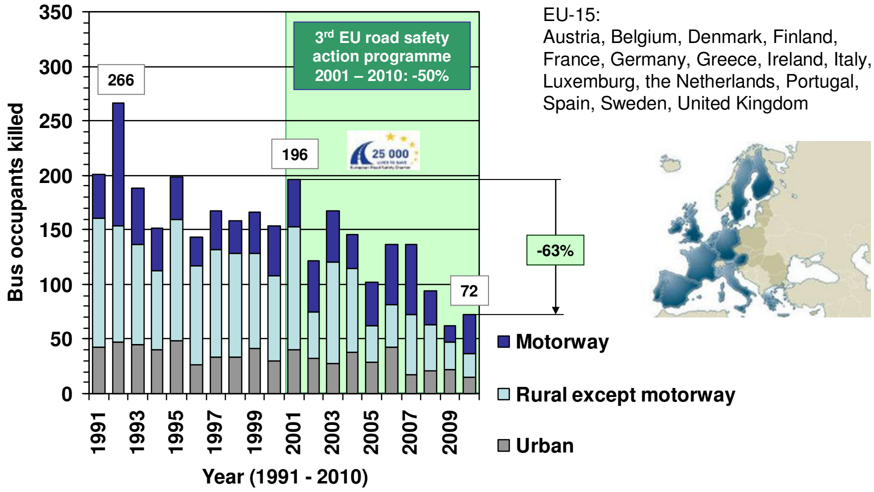
State	Belgique	Bulgaria	Ceská Republica	Danmark	Deutschland	Eesti
Year	2011	2009	2012	2012	2012	2009
Driver	2	0	1	1	0	0
Passengers	0	0	1	0	3	2
State	Éire	Elláda	Españia	France	Hrvatska	Italia
Year	2010	2011	2012	2012	2012	2012
Driver	1	1	0	2	1	1
Passengers	0	3	3	5	7	6
State	Kýpros	Latvija	Luxembourg	Magyarország	Malta	Nederland
Year	2012	2012	2012	2012	2010	2012
Driver	0	0	0	1	0	0
Passengers	0	3	0	2	0	1
State	Österreich	Polska	Portugal	România	Slovenijya	Slovensko
Year	2011	2012	2012	2012	2011	2010
Driver	0	7	0	1	0	0
Passengers	2	11	2	9	0	0
State	Suomi	Sverige	Great Britain	EU-27 = EU-28 without Lietuva*		
Year	2012	2010	2012	-		
Driver	0	1	0	20		
Passengers	1	1	10	72		

* Lietuva is not reporting to CARE

For Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxemburg, the Netherlands, Portugal, Spain, Sweden and the United Kingdom (EU-15) it was possible to identify in CARE the number of bus/coach occupants killed annually from 1991 to 2010 for each year broken down to the location (urban, rural without motorway, motorway) of the accidents, **Figure 1**. The maximum was recorded in 1992 with a total number of 266 killed bus/coach occupants. In 2010, the reported number was 72. Most of these bus/coach occupants died in accidents outside urban areas. The proportions in 2010 are: 15 fatalities urban (21%), 22 fatalities rural without motorway (31%) and 35 fatalities on motorways (49%).

The 3rd European Road Safety Action Programme set the objective of cutting in halve the number of killed road traffic participants for the whole of the European Union (EU-27) over the period 2001 to 2010 [2]. This objective was almost attained by a reduction of 44% from 54,000 to 39,500 (all road users). In the member states considered here (EU-15) the number of bus/coach occupants killed fell from 196 in 2001 to 72 in 2010, i.e. by 63%. This means that bus/coach occupants participated well in the general development towards steadily improved safety levels on the roads of the EU.

Figure 1:
Bus/coach occupants killed per year in road accidents in 15 member states of the European Union (EU-15) from 1991 to 2010 (data source: CARE [1] with last refresh date on March 17, 2014)



CASUALTIES IN BUSES/COACHES ON GERMAN ROADS

In 2012 a total of 3,600 road users died in Germany, 66,279 were seriously and 318,099 slightly injured. Bus/coach occupants formed a very low proportion of these casualties with 3 fatalities, 394 seriously and 5,274 slightly injured. Only 0.08% of the fatalities, 0.6% of the seriously injured and 1.7% of the slightly injured road users are bus/coach occupants. In the German accident statistics fatalities are persons who died within 30 days as a result of the accident. Seriously injured are persons who were immediately taken to hospital for inpatient treatment of at least 24 hours. Slightly injured are all other injured persons. Occupants of buses/coaches are defined as those travelling in a motor coach or bus (tourist bus, bus of the line, school bus) or a trolleybus.

When interpreting the numbers it needs to be noted that only those killed or injured in road accidents are included in the statistics. For example, near Hanover 20 people died in a bus disaster on the A2 Autobahn in 2008. This was not the result of a road accident because the bus caught fire as a consequence of an “internal operation” [3].

The number of bus/coach occupants killed or injured in road accidents annually since 1957 can be extracted from the publications of the Federal Statistical Office [4, 5, 6]. **Figure 2** shows the long-term evolution of the numbers of killed bus/coach occupants up to 2012. The numbers given for 1992 and afterwards apply to the Republic of Germany after the re-unification in 1990 – i.e. both “old and new Laender”. The graph displays that the numbers of killed bus/coach occupants certainly remains at a very low level with sinking long-term trend. But the individual annual figures vary considerably.

The maximum number of fatalities during the stated period was 74 recorded in 1959. In that year the most serious bus accident in Germany since the 2nd World War occurred. In the city of Lauffen at the river Neckar (Baden-Württemberg) a bus travelling over a level crossing was struck by the locomotive of an express train, **Figure 3**. 45 bus occupants were killed [6, 7].

The previous minimum was 2 bus/coach occupants killed in 1998. 3 killed bus/coach occupants were registered in 2012. The substantial variation over time of the annual numbers of fatalities is significantly influenced by individual serious accidents in which a relatively large number of occupants were killed. **Table 2** contains four examples for 1959, 1992, 2007 and 2010.

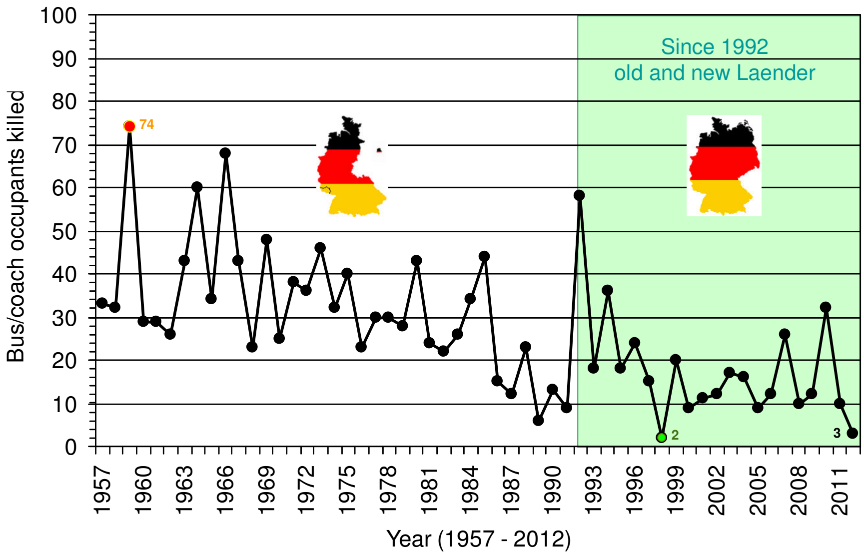


Figure 2: Bus/coach occupants killed in accidents on roads in the Federal Republic of Germany per year from 1957 to 2012 (data source: Federal Statistical Office [4, 5, 6])

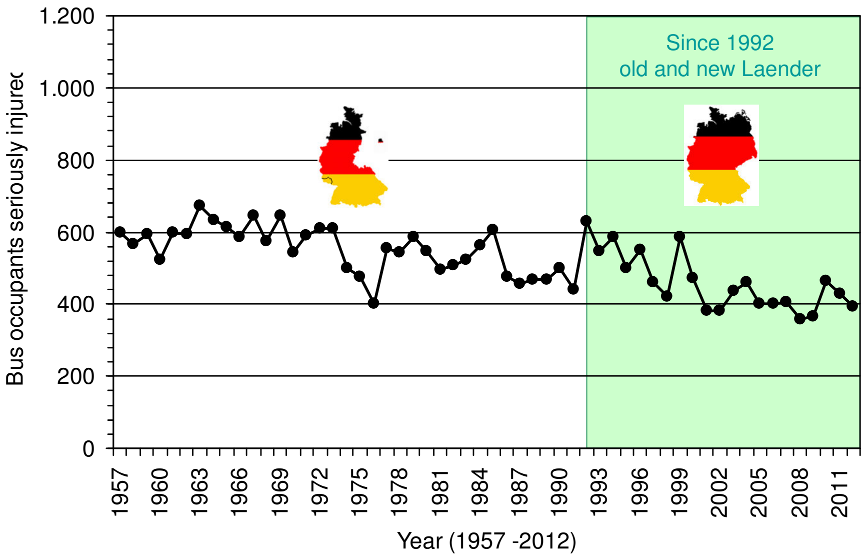
Figure 3: The most serious bus accident in Germany since the 2nd World War occurred on June 20, 1959, in the city of Lauffen at the river Neckar (Baden-Württemberg)

Table 2: Examples of single catastrophic bus/coach accidents which significantly influenced the figure of killed bus/coach occupants in the corresponding year

Accident Date	Accident description	Bus/coach occupants killed in the described accident	Bus/coach occupants killed during the entire year	Share in bus/coach occupants killed during the year
June 1959	Bus struck on a railway level crossing by the locomotive of an express train	45	74	61%
Sept. 1992	Coach tilts after forcing a car and crashes into a guardrail	20	58	34%
June 2007	Truck crashes into the rear end of a coach	13	26	50%
Sept. 2010	Coach crashes into a car and a bridge post after evasion manoeuvre	13	32	41%

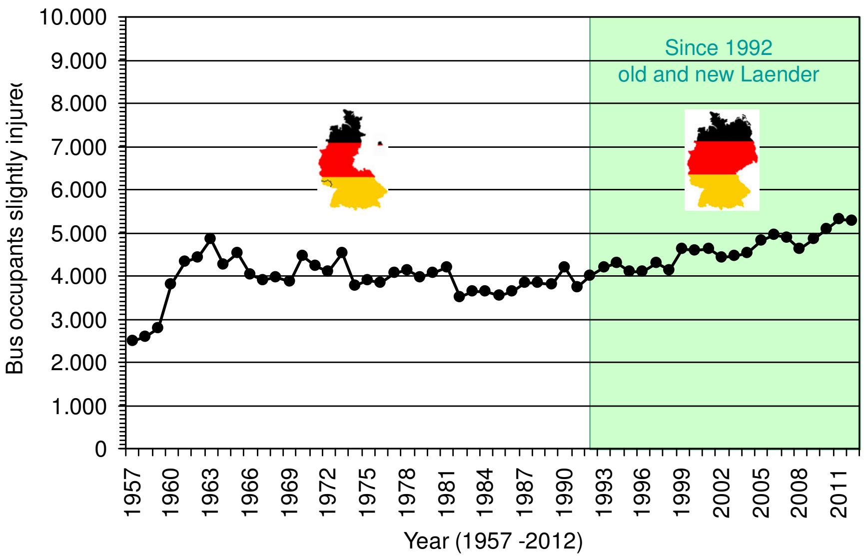
The long-term evolution of the figures of severely injured bus/coach occupants (see **Figure 4**) is less influenced by annual variations than the number of occupants killed. In the 'old Laender' of the Federal Republic of Germany (1957 -1991) brief periods of falling numbers were followed by some clear increases. In the period following the reunification (figures since 1992), a sustained falling trend in the numbers of severely injured occupants could be observed up to now over the long term. This means that bus/coach occupants had their share as well in the general trend offering greater vehicle and traffic safety on German roads. 394 severely bus/coach occupants have been registered for 2012.

Figure 4:
Bus/coach occupants severely injured in accidents on roads in the Federal Republic of Germany per year from 1957 to 2012 (data source: Federal Statistical Office [4, 5, 6])



To complete the picture, the long term evolution of the figures of slightly injured occupants of buses/coaches is displayed in **Figure 5**. Here the figures did grow in the late 1950s and early 1960s to a maximum of 4,846 in 1963. Afterwards this figure more or less trends marginally downwards until the reunification and then it grows again. 5.274 slightly injured bus/coach occupants were registered for 2012.

Figure 5:
Bus/coach occupants slightly injured in accidents on roads in the Federal Republic of Germany per year from 1957 to 2012 (data source: Federal Statistical Office [4, 5, 6])



For more detailed interpretations the figures of casualties for buses/coach occupants can be separated in terms of the particular vehicle function (described in the Federal statistics with “category of road user”). The official statistics differentiate between coaches (tourist bus), urban buses (bus of the line), school buses and trolleybuses (bus electrically propelled trough a trolley line). There is also a category for “other buses” that covers buses/coaches which the police who is on spot responsible for the accident data collection were unable to assign to one of the above-mentioned categories.

According to the statistics available, the low numbers of fatalities and their sub portions alter in wide ranges, **Figure 6**. For the individual years 1998, 2001 and 2006 no killed coach occupants were registered in the official statistics. In other years, such as 2002, 2003, 2007 and 2010 the number of coach occupants killed are dominant compared with the total number of all bus/coach occupants killed. From 1996 to 1998, 2000 to 2006, in 2008, 2010 and 2012 no occupants of school busses lost their life in a road accident. For trolley buses, no killed occupants were registered in all years displayed here. The larger numbers of casualties (i.e. injured and killed) are always dominated by the occupants of urban buses, **Figure 7**.

Figure 6: Fatalities in buses/coaches in Germany per year from 1995 to 2012 broken down into sub-groups corresponding to the function (“category of road user”) of the vehicles (data source: Federal Statistical Office [5])

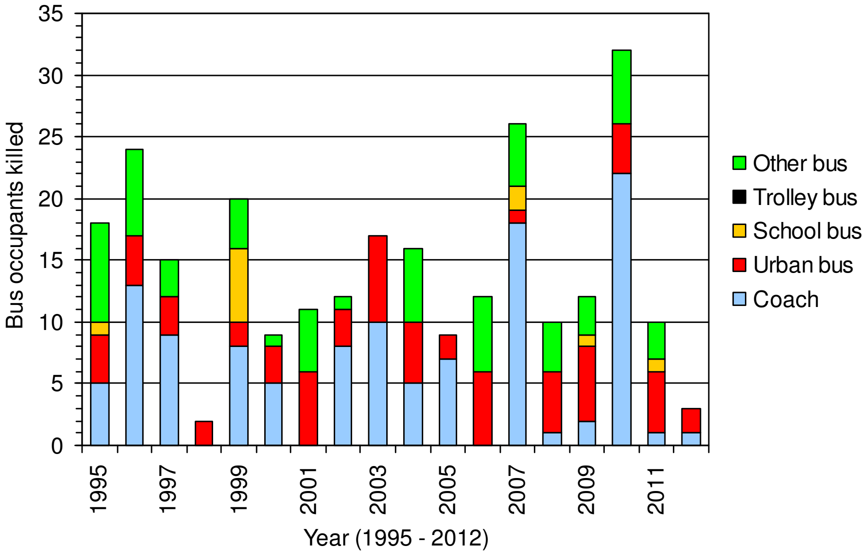
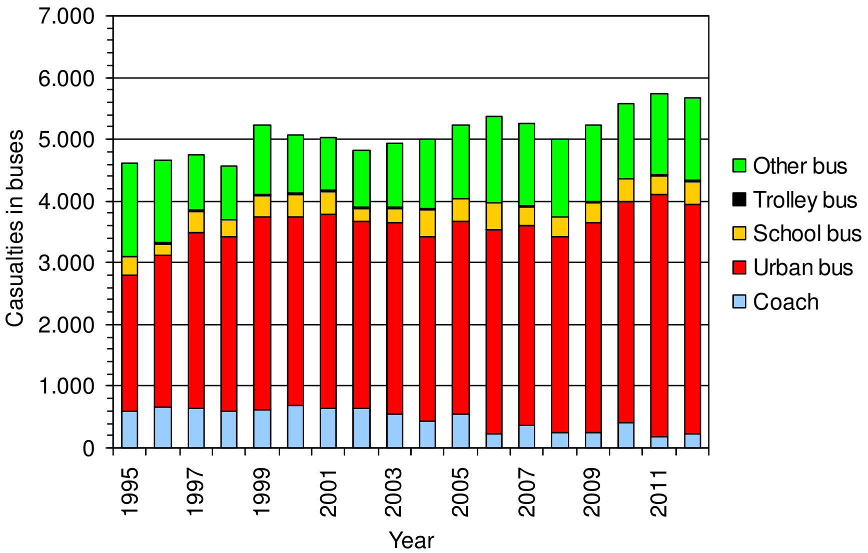


Figure 7: Casualties in buses/coaches in Germany per year from 1995 to 2012 broken down into sub-groups corresponding to the function (category of road user) of the vehicles (data source: Federal Statistical Office [5])



In individual years the number of fatalities or casualties associated with "other buses" is still relatively high. For example, 6 fatalities in 2010 representing 19% of the total of 32 killed bus/coach occupants were registered as occupants of "other buses". It can, therefore, be assumed that the real numbers of casualties in urban buses, coaches and, where appropriate, school buses could be as well greater than shown by the statistics.

The over-riding objective is to steadily reduce the absolute number of persons killed in traffic accidents. This is reflected by Vision Zero, a worldwide strategy initiated in Sweden and promoted in Germany by the German Road Safety Council (DVR) [9]. The Accident Statistics show that Vision Zero had already become a “temporary reality”, not only for the occupants of trolley buses and school buses, but also for coach occupants on German roads during individual years.

Furthermore, accident records especially for coaches demonstrate the importance of the constantly expressed statement that “every traffic death is one death too many”. The public memory retains severe individual coach accidents for a long time but takes no account of the individual years in which no coach occupants die. Severe coach accidents always provide occasion to refer to the fact that “according to the statistics, the long-distance coach is the safest mode of passenger transport on roads”. However, in a current view to dramatic real consequences of an accident, the abstract statistics fade into insignificance. So there is only a limited opportunity to persuade the public to accept on a sustained basis the desired image that coach travel is "the safest way to make a land journey". With this background it can be seen that there needs to be an over-riding strategic aim for all those involved, to take appropriate measures to ensure that the number of bus/coach accidents remains as low as possible, but also that the consequences of a serious accident, which can never be entirely eliminated, are kept to an absolute minimum.

RISK INDICATORS

To be able to compare the safety of vehicle occupants (drivers and passengers) it is customary to use several risk indicators. Illustrations of how the values of three often used indicators have developed over time are given below.

Casualties per 100,000 vehicles registered

Indicator values calculated as killed occupants per 100,000 vehicles registered are published annually with the official German statistics [4]. Figures for 2012 are shown in **Table 3**. This kind of indicator is easy to calculate using official figures of casualties (killed or injured occupants) which are published from official sources [4, 5, 6]. Here, figures of registered buses/coaches are reported as well.

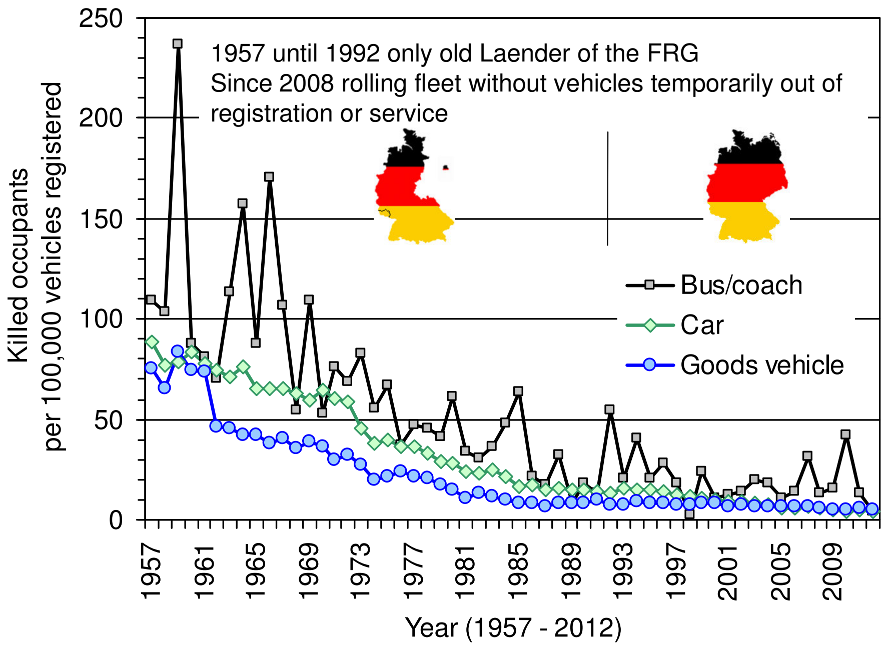
The figures for casualties relate to the numbers of fatally, seriously or slightly injured occupants of German (and foreign!) vehicles which are involved in accidents on German roads. Used as scale bases are the corresponding figures of vehicles registered (in Germany only!). It should be noted, that from 2008 onwards vehicles which are temporarily out of registration or service are excluded from the official figures of vehicles registered. This means that since 2008 the calculated indicator values are really based on the figures of vehicles in the rolling stock.

Table 3: Killed occupants per 100,000 vehicles registered in Germany
as published for the year 2012 with the annual official statistics [4]

Vehicle category	Motor vehicles	Cars	Motorcycles	Mofa/Mopeds	Goods vehicles
Killed occupants per 100.000 vehicles registered	4,9	4,2	15,0	4,5	4,7

Figure 8 compares the evolution of the indicator values related to buses/coaches, cars and goods vehicles from 1957 to 2012. Since the data only applies to re-unified Germany from 1993 onwards, for the time up to and including 1992 only figures recorded in the statistics of the 'old Laender' of the Federal Republic of Germany (FRG) have been taken into account.

Figure 8:
Risk indicator values for occupants of buses/coaches, cars and goods vehicles calculated as killed per 100,000 vehicles registered in the Federal Republic of Germany from 1957 to 2012 (Data source: Federal Statistical Office, [4, 5, 6])



Here too, the influence of single severe bus/coach accidents causing a widely varying pattern of bus/coach occupants killed annually can be seen. There was a significant reduction of the indicator values until and including the 1980s for all three vehicle categories displayed. This confirms the general trend towards a higher level of road traffic safety. For later years the curves flattens out.

It is noteworthy that the indicator values for car occupants and for goods vehicle occupants have converged. 4.2 occupants of cars and 4.7 occupants of goods vehicles have been killed per 100,000 vehicles of the corresponding fleets in 2012. In 1998 when only 2 bus/coach occupants were killed and the number of buses/coaches registered was 83,285 the corresponding indicator value was 2.4 occupants killed per 100,000 buses/coaches. Such a favourable result was not achieved in any other year when the indicator value for buses/coaches was usually greater than for cars and goods vehicles. In 2010 with 32 killed bus/coach occupants and 76,433 of such vehicles registered, the indicator value is calculated to 41.9 killed occupants per 100,000 vehicles. As already mentioned before, such effects are due to the significant unfavourable influence exerted by relatively large numbers of occupants of buses/coaches who were killed in individual accidents. For 2012 the indicator value is 3.9 occupants killed per 100,000 buses/coaches and lays in the same region as the values for cars and gods vehicles.

To complete the picture, **Figures 9** and **10** display the indicator values based on the figures of vehicles registered for the seriously and slightly injured occupants of buses/coaches, cars and goods vehicles. In all the years from 1957 to 2012 this indicator shows greater values for bus/coach occupants than for occupants in cars or goods vehicles. This is as well due to the much greater figure of occupants in a bus/coach. If an accident occurs, the potential for a greater figure of occupants being slightly or seriously injured increases correspondingly.

In recent years the indicator values for cars and goods-vehicle occupants have converged with a clear trend. 68 severely injured and 435 slightly injured car occupants respectively 58 severely injured and 249 slightly injured goods-vehicle occupants, each per 100.000 vehicles registered, are the results for

2012. The corresponding values for seriously injured bus/coach occupants remains nearly constant around 500 since the end of the 1990s. In the same period for slightly injured bus/coach occupants the indicator value was growing up to 6.941 in 2012.

Figure 9: Risk indicator values for occupants of buses/coaches, cars and goods vehicles calculated as seriously injured per 100,000 vehicles registered in the Federal Republic of Germany from 1957 to 2012 (Data source: Federal Statistical Office, [4, 5. 6])

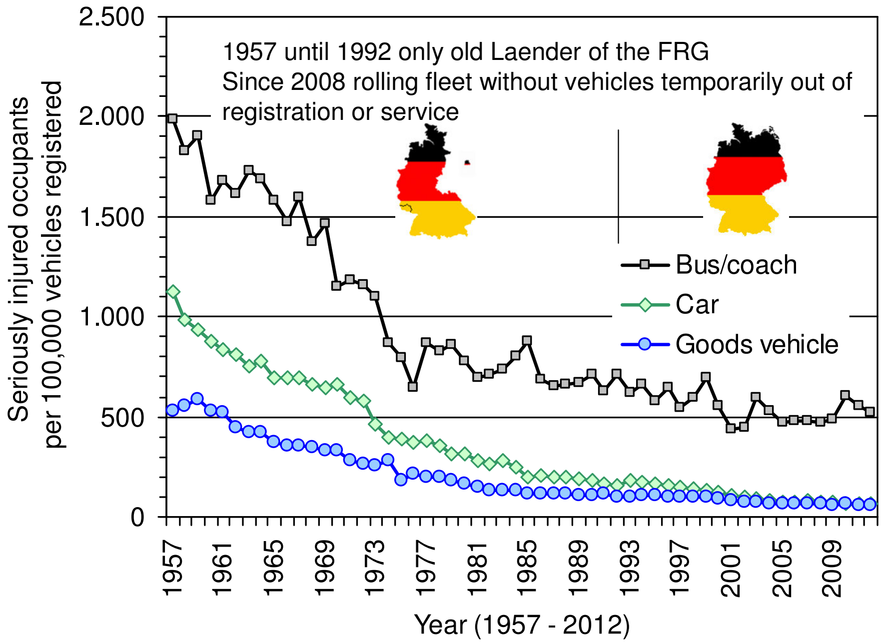
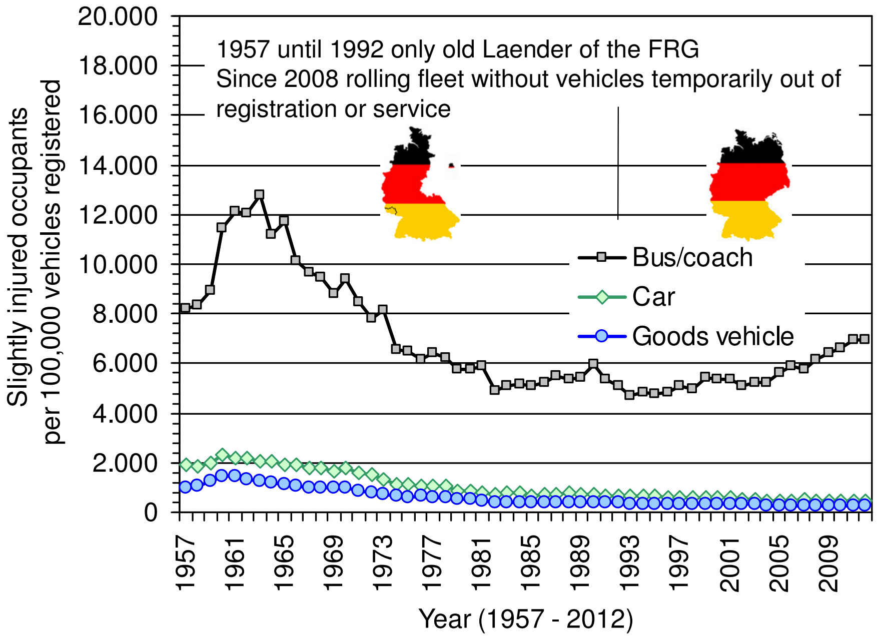


Figure 10: Risk indicator values for occupants of buses/coaches, cars and goods vehicles calculated as slightly injured per 100,000 vehicles registered in the Federal Republic of Germany from 1957 to 2012 (Data source: Federal Statistical Office, [4, 5, 6])



The indicator related to the total rolling-stock figures of vehicles is quite abstract. It indeed is suitable for recognising and comparing different categories of vehicles. However, it does not permit a real derivation of the level of risk to which individual vehicles and their occupants are exposed because that risk is additionally related to both vehicle mileage travelled and the number of occupants in a vehicle.

Casualties per 1 billion vehicles-kilometres travelled

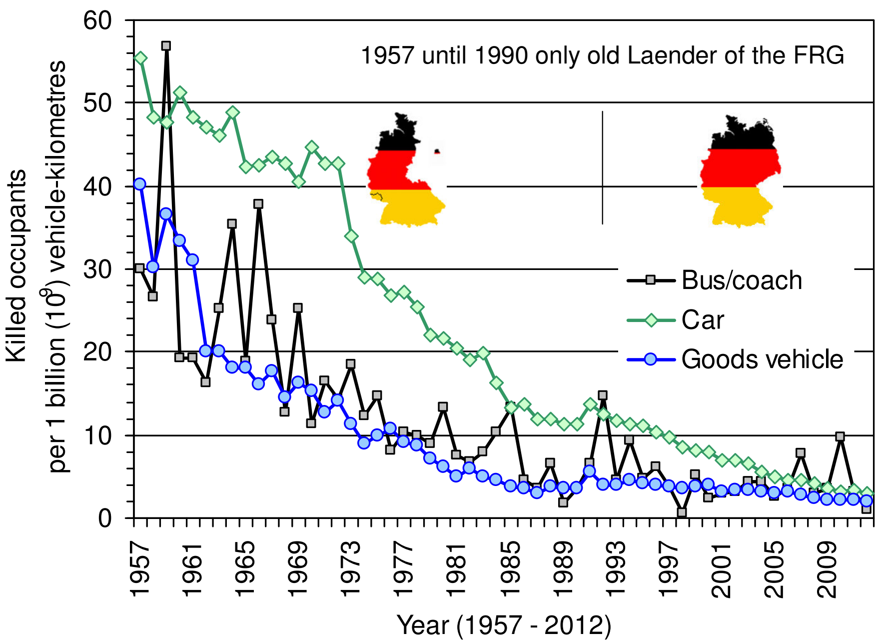
Indicator values describing casualties and fatalities for all road users (including cyclists and pedestrians) per 1 billion (10^9) vehicle-kilometres travelled are published annually in the official German statistics [4] as well. Here, 547 casualties and 5.1 killed, each per 1 billion vehicle-kilometres are reported for 2012.

Such risk indicators also can be calculated as the relation between the numbers of occupants killed, severely or slightly injured and the total mileage annually travelled per vehicle in the corresponding category. They can be clearly explained: The inverse proportion corresponds to the average risk that an individual occupant of a vehicle will be killed (or severely injured or slightly injured) in a road traffic accident after travelling a specific mileage.

Data necessary for the calculations are published for certain vehicle categories in the Federal statistics [4, 5, 6] and in publications from the Deutsches Institut für Wirtschaftsforschung (DIW) [10]. The mileages result from the use of a calculation model. One of the determining factors is the total annual fuel consumption in Germany. The result is called as "natives mileage". This means the mileage of registered German vehicles including their mileage travelled on foreign roads [11].

Figure 11 displays the evolution of this indicator values for fatally injured occupants in buses/coaches, cars and goods vehicles from 1957 to 2012. Again the period from 1957 to 1990 covers only the "old Laender" of the FRG and from 1991 onwards the "new Laender" are included.

Figure 11:
Risk indicator values for occupants of buses/coaches, cars and goods vehicles calculated as killed per 1 billion (10^9) vehicle-kilometres for the Federal Republic of Germany from 1957 to 2011 (Data sources: Federal Statistical Office, [4, 5, 6], Deutsches Institut für Wirtschaftsforschung DIW [10])

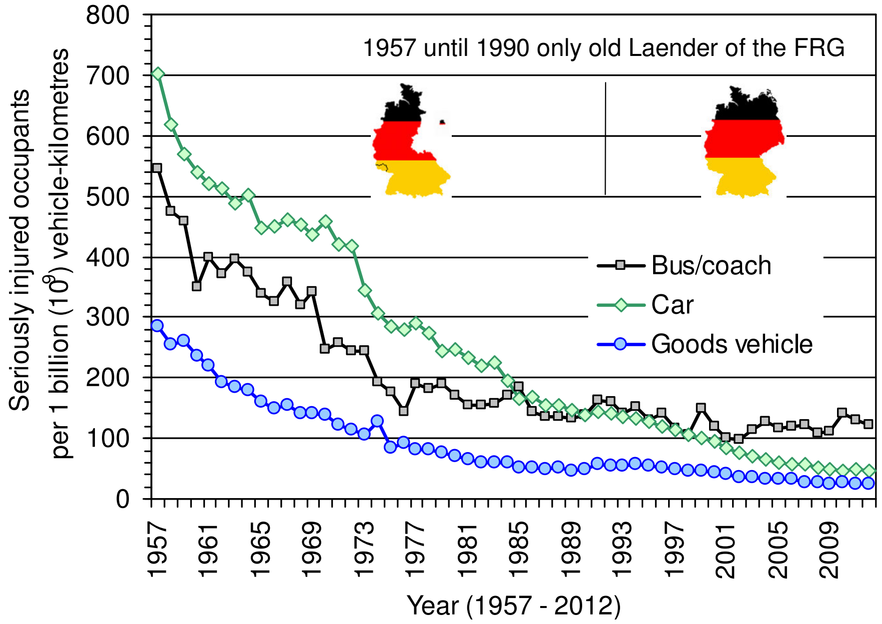


Here too, for all three vehicle categories clear trends to smaller indicator values are displayed, which indicate sustainable progress in road traffic safety. This is most significant for cars but can be seen with smaller extent for the occupants of goods vehicles and for buses/coaches as well. As far as buses/coaches are concerned, there is again a considerable influence of severe accidents in individual years which widely vary the annual indicator values. Until 2012 the three lines converged to values of 0,9 killed occupants per 1 billion vehicle-kilometres for bus/coach occupants, respectively 2.9 for car occupants and 1.9 for goods-vehicle occupants.

In **Figure 12** the evolution of the corresponding indicator values for seriously injured occupants is displayed. Over the long term the curve for cars starts at the highest level, crosses the curve for bus/coaches in 1990 and is then with smaller values closer to the curve for goods vehicles. In 2012 the indicator value is 123 seriously injured bus/coach occupants, 47 seriously injured car occupants and

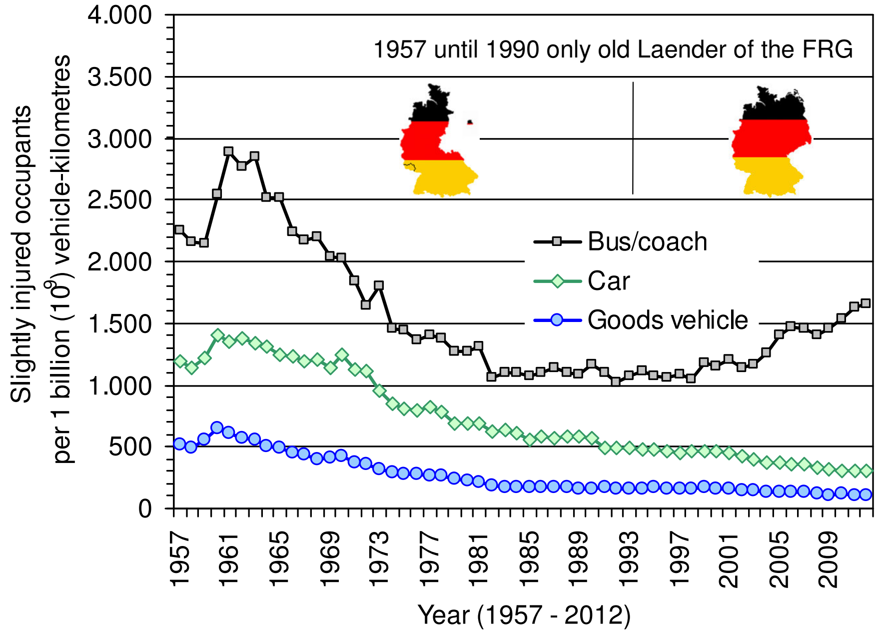
24 seriously injured goods vehicle occupants, each per 1 billion vehicle-kilometres travelled. It is remarkable, that in contrast to the values for cars and goods-vehicles the values for buses/coaches did not further decline since 2001/2002.

Figure 12: Risk indicator values for occupants of buses/coaches, cars and goods vehicles calculated as seriously injured per 1 billion (10^9) vehicle-kilometres for the Federal Republic of Germany from 1957 to 2011 (Data sources: Federal Statistical Office, [4, 5, 6], Deutsches Institut für Wirtschaftsforschung DIW [10])



To again give the complete picture, **Figure 13** shows the corresponding curves for the slightly injured occupants. Similar to the evolution of slightly injured occupants per 100.000 vehicles registered (see Figure 10) the curve for buses/coaches is on the highest level and shows increasing values since the end of the 1990s. Values for 2012 are 1,653 slightly injured bus/coach occupants, 304 slightly injured car occupants and 102 slightly injured goods vehicle occupants, each per 1 billion vehicle-kilometres.

Figure 13: Risk indicator values for occupants of buses/coaches, cars and goods vehicles calculated as slightly injured per 1 billion (10^9) vehicle-kilometres for the Federal Republic of Germany from 1957 to 2011 (Data sources: Federal Statistical Office, [4, 5, 6], Deutsches Institut für Wirtschaftsforschung DIW [10])



Casualties per 1 billion person-kilometres

Casualties per billion (10^9) person-kilometres is a further indicator by which the transport performance of vehicles can be considered. Indicator values calculated as fatalities per 1 billion person-kilometres are often used by the federal statistical office to compare the safety of public passenger transport (buses, underground railway and similar modes, passenger trains) to the risk of car occupants. This indicator as well can be clearly explained: Its value corresponds to the average figure of occupants who died (or are injured) as the consequence of a road accident after the vehicle has travelled a mileage of 1 billion kilometres.

For the period 2007 to 2011 some values are published as shown in **Table 4** [12]. For public transport modes the values are calculated using the figures of killed passengers only (without driver and other staff). For cars the value is calculated using the figure of killed occupants (driver and passengers). This means for a car the driver is seen as a “passenger” as well. Taking into account all occupants with the additional consideration of killed bus/coach drivers results in a light shift of the risk value from 0.23 to 0.29 for all bus/coach occupants, **Table 5**.

Table 4: Risk indicator values calculated as killed occupants/passengers per 1 billion person-kilometres (1 billion = 10^9) for different modes of transport in Germany for the period 2007 to 2011 (Source: Federal Statistical Office [12])

Vehicle category	Car	Bus	Underground railways and similar modes	Passenger train
killed occupants /passengers* per 1 billion person-kilometres	2.49	0.23	0.04	0.04

*for cars calculated using the figures of killed occupants (driver and passenger), for other modes calculated using the figures of killed passengers only

Table 5: Risk-Indicator values calculated as killed per 1 billion person-kilometres for bus/coach occupants (driver and passengers) in Germany for the period 2007 to 2011 (Data source: Federal Statistical Office [4, 6])

Year	Killed bus/coach occupants			Bus/coach transport performance [10^9 person-km]	Risk indicator values [killed per 1 billion person-kilometres]		
	drivers	passengers	occupants		drivers	passengers	occupants
2007	7	19	26	65,387	0.11	0.29	0.40
2008	1	9	10	63,592	0.02	0.14	0.16
2009	3	9	12	62,097	0.05	0.14	0.19
2010	5	27	32	61,743	0.08	0.44	0.52
2011	1	9	10	61,367	0.02	0.50	0.16
Mean value	3.4	14.6	18	62,837	0.05	0.23	0.29

Risk indicators related to the transport performance are "classical" measures indicating the bus/coach with its large number of occupants to be the safest means of road travel. Corresponding to figures published in the official statistics the evolution of the values for fatalities and casualties of occupants of cars, goods vehicles, coaches in non-scheduled traffic (long-distance coach) and urban buses (line traffic) from 1995 to 2012 can be calculated with results displayed in **Figure 14** and **Figure 15**.

For cars and goods vehicles the figures of person-kilometres are based on the reported figures of their annual mileage [10] and on calculated figures of occupants per vehicle in accidents with personal injury which are published in the official statistics as well [4, 5]. As shown in **Table 6** for car occupants the calculated figures of occupants per vehicle range from 1.43 to 1.56 for the period from 1995 to 2012. In the same way (but not shown here with a table) for goods vehicles 1.21 to 1.26 occupants per vehicle can be calculated. For coaches in non-scheduled traffic and buses in line traffic, the figures of their mileage are reported by official statistics directly [6].

Table 6: Calculated figures of occupants per car and of transport performance of cars with the figures for occupants killed per 1 billion person-kilometres as the final result using figures published in official statistics [4, 5, 10]

Year	Car occupants killed published in [4, 5]	Mileage of cars [10^9 km] published in [10]	Cars involved in accidents with personal injury for which the figure of occupants is known published in [4]	Known figures of car occupants published in [4]	Occupants per car calculated	Transport performance of cars [10^9 pers.-km] calculated	Occupants killed per 10^9 pers.-km calculated
1995	5,929	535.1	499,066	779,192	1.56	835.5	7.1
1996	5,622	539.5	482,593	750,045	1.55	838.5	6.7
1997	5,249	542.7	485,462	749,940	1.54	838.4	6.3
1998	4,741	550.8	486,102	744,383	1.53	843.4	5.6
1999	4,640	566.2	502,732	766,102	1.52	862.8	5.4
2000	4,396	559.5	486,158	736,056	1.51	848.0	5.2
2001	4,023	575.5	478,463	721,257	1.51	867.5	4.6
2002	4,005	583.6	459,454	690,916	1.50	877.5	4.6
2003	3,774	577.8	435,565	651,891	1.50	864.8	4.4
2004	3,238	590.4	417,800	621,770	1.49	878.6	3.7
2005	2,833	578.2	405,392	601,042	1.48	857.2	3.3
2006	2,683	583.9	392,131	577,163	1.47	859.4	3.1
2007	2,625	587.5	399,655	585,251	1.46	860.4	3.1
2008	2,368	584.6	374,758	544,662	1.45	849.6	28
2009	2.110	595.0	365,289	528,965	1.45	861.7	2.4
2010	1,840	599.0	343,627	497,737	1.45	867.7	2.1
2011	1,986	608.8	358,358	515,875	1.44	876.4	2.3
2012	1,791	610.1	354,144	506,736	1.43	872.9	2.1

As the graphs display, for killed occupants of urban buses very low risk factors are given, without any exception. In 2012 that risk factor was 0.05 occupants killed per 1 billion person-kilometres.

The risk for occupants of long-distance coaches generally is very low, too. In this instance, however, because of the relatively high number of persons killed in individual years (2007: 18 fatalities, 2010: 22 fatalities), the risk attached to these vehicles is in some years significantly greater than for urban buses. For 2010 there is a value of 1.0 occupants in long-distance coaches killed per 1 billion person-kilometres. For 2011 this value was dropped down to 0.1 and for 2012 it remained with a value of 0.05 on a very low level.

Figure 14:
Risk indicator values for occupants of urban buses, coaches, cars and goods vehicles calculated as killed occupants per 1 billion person-kilometres for Germany from 1995 to 2012, Data sources: Federal Statistical Office, [3,5], Deutsches Institut für Wirtschaftsforschung DIW [10])

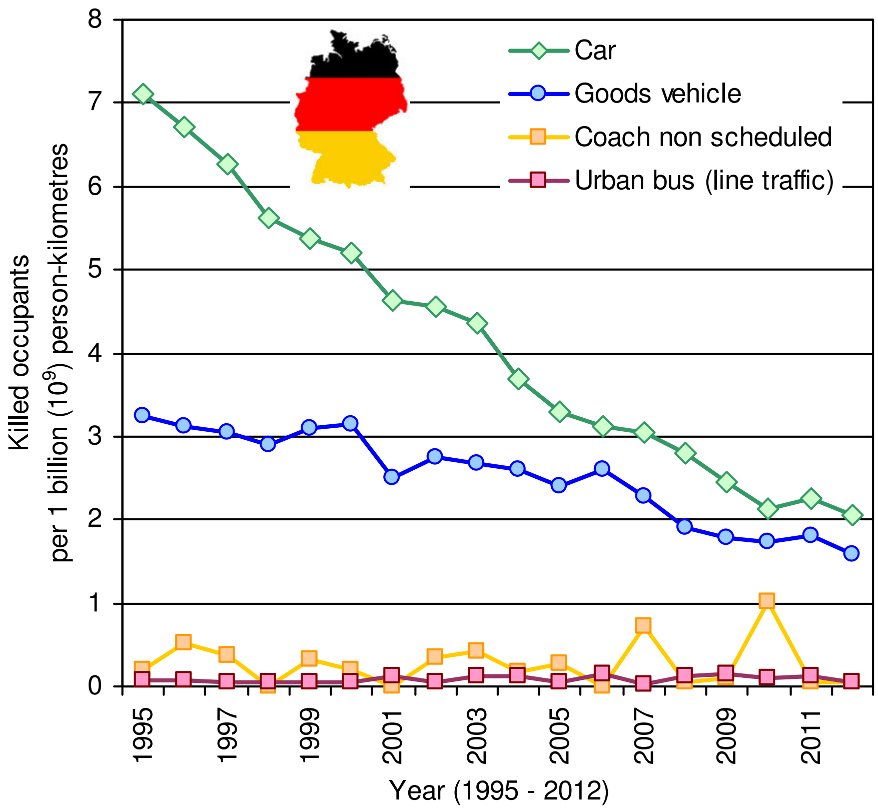
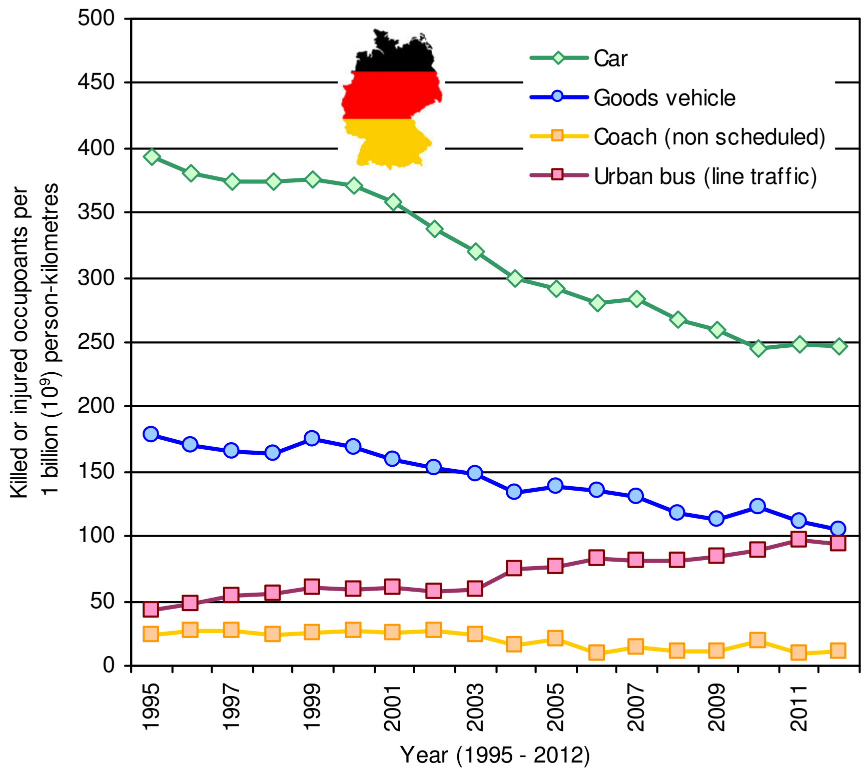


Figure 15:
Risk indicator values for occupants of urban buses, coaches, cars and goods vehicles calculated as killed or injured occupants per 1 billion person-kilometres for Germany from 1995 to 2012, Data sources: Federal Statistical Office, [3,5], Deutsches Institut für Wirtschaftsforschung DIW [10])



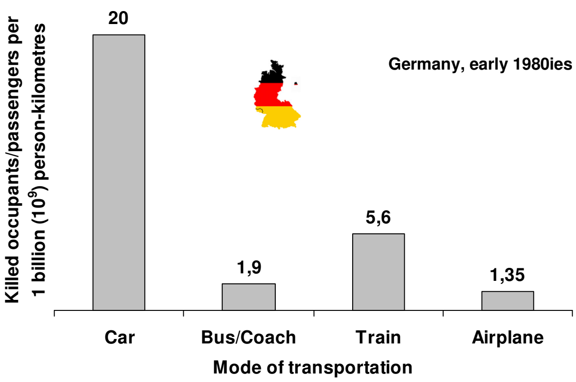
In earlier years these values of the fatality risk indicators related to transport performance for the occupants of cars and goods vehicles were still significantly higher than for the occupants of buses/coaches. As a consequence of the sustained evolution towards higher levels of safety for vehicles and road traffic as a whole, the values of the corresponding risk indicators for the occupants of these vehicles have almost approached that of the occupants of buses/coaches. For 2012 the values are 2.1 for car occupants and 1.6 for goods-vehicle occupants killed per 1 billion person-kilometres.

Concerning the casualty risk indicator values the graphs show significantly higher risks for car occupants despite the corresponding curve moved sustainably downwards. For 212 the calculated value is 248 car occupants killed or injured per 1 billion person-kilometres. The curve for goods vehicle occupants displays considerable decreasing indicator values as well. For 2012 a value of 105 goods-vehicle occupants killed or injured per 1 billion person-kilometres was calculated.

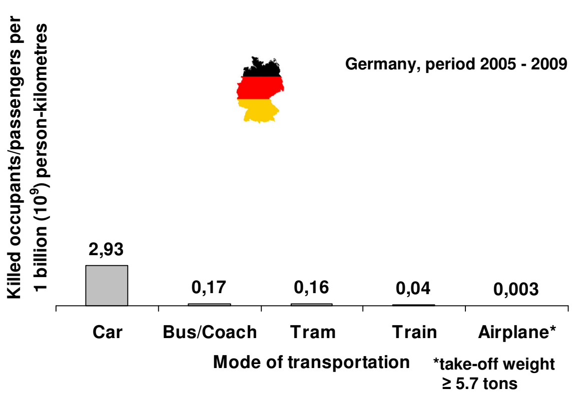
It is remarkable, that the risk of being killed or injured for the occupants of urban buses is growing whereas the corresponding risk for the occupants of coaches tends downwards. For 2012 the results are 94 occupants in urban buses and 11 occupants of coaches, each killed or injured per 1 billion person-kilometres.

General comparison of the fatality risk with other modes of long-distance travel

To compare the safety of buses with other modes of long-distance travel respectively public transport, from time to time there are official figures published displaying the fatality rates for the passengers of buses/coaches, trams, trains and airplanes with the risk of occupants (drivers and passengers) in cars. **Fig. 16** displays corresponding risk values for Germany reported by Langwieder et al. for the early 1980s [13] and by Vorndran for the period 2005 to 2009 [14]. First of all, the large reduction of the recent figures compared to the older ones is expressive. For example 1.9 bus/coach passengers have been killed per 1 billion person-kilometres in road accidents in the early 1980s. The corresponding risk-value for the period 2005 to 2009 is reduced by 99 % down to 0.17.



Source: Langwieder et al., 1985 [13]



Source: Vorndran, 2010 [14]

Figure 16: Comparisons of risk-indicator values related to killed passengers of buses/coaches, trams, trains, airplanes and occupants of cars, each per 1 billion person-kilometres for Germany in the early 1980ies and in recent years

As reported by Langwieder, in the early 1980s the risk value for car occupants (20) was 11 times higher that the value for bus/coach passengers (1.9). The figures publisehd by Vorndran displays that in the period 2005 to 2009 the risk-value for car occupants (2.93) is 17 times higher than tat for bus/coach passengers (0.17). For the early 1980s the values show that the bus is even saver than the train (5,6 killed passengers per 1 billion person-kilomteres) and on the same safety level as the airplane (1.36 killed passengers per 1 billion person-kilometres). For the period 2005 to 2009 the risk values for buses/coaches and trams are with 0.17 and 0.16 on the same low level for both modes of transport and air travel is with a risk value of 0.003 clearly the safest mode of transport (for airplanes with a take-off weight above 5.7 tons).

Additionally, it is of interest how the risk values for car occupants alter when they are calculated separately for driver and passengers. As shown with re-calculated figures in **Table 7**, this separation indeed makes a remarkable difference. While 2.94 car drivers respectively 2.90 car occupants have been killed per 1 billion person-kilometres the corresponding value (based on the same value for the driving performance) is only 0.75 car passengers killed per 1 billion person-kilometres. But this value is still clearly higher (more than 4 times) as the value of 0.17 bus/coach occupants killed per 1 billion person-kilometres. Considering that not all car mileages are travelled with a passenger on board it becomes sure that for the passengers a bus journey is really much safer than a car journey.

Table 7: Risk-Indicator values calculated as killed per 1 billion person-kilometres for car occupants (driver and passengers) in Germany for the period 2005 to 2009 (Data source: Federal Statistical Office [4, 6])

Year	Killed car occupants			car transport performance [10^9 person-km]	Risk indicator values [killed per 1 billion person-kilometres]		
	drivers	passengers	occupants		drivers	passengers	occupants
2005	2,097	736	2.833	857,198	2.85	0.86	3.30
2006	1,987	696	2.683	859,428	2.85	0.81	3.12
2007	1,984	641	2.625	860,392	3.10	0.75	3.05
2008	1,742	626	2.368	849,624	2.78	0.74	2.79
2009	1,573	537	2.110	861,668	2.93	0.62	2.45
Mean value	1,877	647	2.524	857,662	2.90	0.75	2.94

CONCLUSUIONS AND OUTLOOK

To describe the safety of vehicles for their occupants (driver and passengers) some risk-indicators are in use. The interpretation of such indicators and their values differ depending on the data used for the calculation. It seems that for a complete view on recent figures and historical evolutions not only one indicator should be taken into account. This article gave some examples. All in all the statistics show very low numbers of bus/coach occupants killed or injured in road accidents with corresponding low risk indices. Although the safety of occupants of cars and goods vehicles gained on, the bus/coach is still the safest vehicle for the occupants (drivers and passengers) and especially for the passengers concerning travel on land.

Nevertheless, in view of the historic evolution and good results recently, the over-riding strategic aim is still valid to take appropriate measures to ensure first that the number of bus/coach accidents remains very low and second that the consequences of a serious accident, which can never be entirely eliminated, are kept to an absolute minimum.

Essential improvements were achieved in the active safety and as well in the passive safety of buses/coaches. From a technical point of view it can be stated that today's buses/coaches are safer than at any time before [15]. In the field of passive safety of coaches these measures become most effective when all occupants wear their seat belts throughout the journey. Since the belt use rate in coaches is still very low, the full safety potential of these vehicles could be even further exploited in the future if all occupants would use their safety belt during the journey.

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A new methodology for determining accident and injury contributing factors, and its application to road accidents on the Mumbai–Pune Expressway

M Patel, S Kumar, S Balakumar, A Patel, M Bhuvanesh, M Painter, R Rajaraman, A M Hassan*, J Padmanaban**

JP Research India Pvt. Ltd., Pune, Maharashtra, India
*Former Research Fellow - Birmingham University, UK
**JP Research Inc. 1975 W. El Camino Real, Suite 300, Mountain View, California 94040, USA

Abstract - Road accidents are typically analyzed to address influences of human, vehicle, and environmental (primarily infrastructure) factors. A new methodology, based on a "Venn diagram" analysis, gives a broader perspective on the probable factors, and combinations of factors, contributing both to the occurrence of a crash and to sustaining injuries in that crash. The methodology was applied to 214 accidents on the Mumbai–Pune expressway. Factors contributing to accidents and injuries were addressed. The major human factors influencing accidents on this roadway were speeding (30%) and falling asleep (29%), while injuries were primarily due to lack of seat belt use (46%). The leading infrastructure factor for injuries was impact with a roadside manmade structure (28%), and the main vehicle factor for injuries was passenger compartment intrusion (73%). This methodology can help identify effective vehicle and infrastructure-related solutions for preventing accidents and mitigating injuries in India.

INTRODUCTION

The World Health Organization (WHO), in its *Global Status Report on Road Safety 2013*, observes that road traffic injuries are "the leading cause of death for young people aged 15-29" worldwide, and that, while many countries have taken steps to reduce fatalities from road traffic accidents, the total "remains unacceptably high at 1.24 million per year" [1].

To find effective solutions to this problem, an in-depth understanding of the problem is essential. Given the complexity of crash events and their causes, this is often a case of "easier said than done." The first requirement, of course, is good data on real world crashes. The second is a means of using the data to understand what happens in these crashes and how both the crash events and their injury consequences could best be avoided. The focus of this study was development and application of a methodology to address this second requirement.

Background

The traditional wisdom regarding road accidents is that driver error is generally the root cause. In a comprehensive review of various approaches for using crash data to create safer road conditions, Stigson et al. [2] point out that, since 1980 the focus has been on the three factors that contribute to an accident: human, vehicle and road infrastructure/environment and their interactions. As that paper succinctly summarizes, early attempts to look at causation tended to link vehicle and environmental factors to the human factor, with the result that drivers and other road users were identified as "the sole or a contributory factor in approximately 95% of all crashes".

Not surprisingly, such a human factors-centered approach fails to address the vehicular and infrastructural problems that are equally significant in contributing to an accident, for an accident is not a singular event but a "dynamic system" [2]. In "Risk Management in a Dynamic Society: A Modelling Problem", Rasmussen examined the causal foundation of hazardous industrial and transport accidents and rejected the idea of looking at separate elements in isolation in favor of considering the dynamic combination of all possible paths to and causes of failures [3]. That paper notes that while "it is often concluded in accident reviews that 'human error' is a determining factor … multiple contributing errors and faults are normally found".

Stigson et al. brings that point back to road accidents by applying one year of real-world fatal crash data to an analysis of the Swedish Road Administration (SRA) model for a safe transport system. The SRA model employs a Venn diagram approach and includes interactions between road users, vehicles and "the road" (that is, the road environment, including infrastructure) — essentially all the factors that together form the road transport system. The Stigson paper found that 93% of the fatal crashes in that study were classifiable using the SRA model, and that, "of the three components, the road was the one that was most often linked to a fatal outcome" [2].

Approach

For the current study, a Venn diagram approach was applied to a crash investigation of the Mumbai–Pune Expressway, in India, to determine the contributing factors for accidents occurring on the expressway. Implementing the SRA model to Indian conditions posed some difficulties that required a modified approach. For example, there is no set benchmark for ideal conditions (required by the SRA model). This made it impossible to correlate the factors based on their ratings, as had been done by Stigson et al. for the Swedish crash study. The Stigson paper reports correlations based on the European New Car Assessment Program (EuroNCAP) ratings for cars and European Road Assessment Program Road Protection Score (EuroRAP RPS) ratings for roads.

In the absence of such standard rating systems, the SRA model needed to be refined to reflect the Indian conditions. The new method was then tested by application to all accidents occurring on the Mumbai–Pune Expressway over a period of 12 months. Like the SRA model, this method was used to help determine the contributing factors leading to each accident and, separately, to injuries sustained in each accident. This new methodology, developed from the SRA model, has proven to be useful not only for identifying contributing factors but also for ranking them based on the number of accidents these factors have influenced. This ranking is to help policy makers, decision makers and road safety stakeholders in planning cost effective road safety investments using data-driven road safety strategies.

This paper gives details of the contributing factors methodology, its application to crashes, and the results and conclusions from the examination of road accidents on the Mumbai–Pune Expressway.

METHODOLOGY

The study included 214 accidents that occurred on the Mumbai Pune Expressway from October 2012 to October 2013. The accidents are part of an ongoing in-depth investigation under the RASSI (Road Accident Sampling System–India) initiative, a database development effort supported by a consortium of automobile original equipment manufacturers and JP Research India [4]. Appendices A and B present some of the information captured and coded as part of detailed case investigations on Indian roads.

As illustrated in Table 1, two accidents with the same accident type can have very different injury outcomes. In Case 1, the driver slept and went off-road on his left. The car was lightly damaged and the driver, who was belted, walked away with no major injuries. In Case 2, the driver of a similar car slept and went off-road, but to the right side into the median space. This car impacted a concrete barrier. The car experienced severe intrusions and the unbelted driver was fatal. In both circumstances the causal scenario is the same: a sleepy driver, but the outcomes are drastically different. In order to address this disparity, the accidents were analyzed to determine the contributing factors that led to each accident and, separately, to the resulting injuries. Analyzing the accidents separately for accident causation and injury causation gives a broader understanding of each accident.

Establishing a baseline

In keeping with the structure set up for the SRA, certain conditions were assumed to be the "ideal conditions", not meeting which would be considered a failure of that specific factor (human, vehicle or infrastructure). These are listed in brief in Table 2. Keeping the ideal as the baseline, each accident was coded for accident causation factors and injury causation factors.

Table 1. Example cases showing different injury outcomes from the same triggering factor

Points of comparison	**Case 1**	**Case 2**
Scene photos *Taken along the direction of vehicle's travel*		
Vehicle photos *Damages sustained by the vehicle*		
Injury severity	No injury	Fatal
Contributing factors *Leading to an accident*	Sleepy driver	Sleepy driver Narrow shoulder width
Contributing factors *Leading to an injury*	Not applicable (No injury)	Manmade concrete barrier Seatbelt not used by occupants Passenger compartment intrusions

Table 2. Ideal conditions assumed for coding accident and injury causation

Category	Accident ideals	Injury ideals
Human	• Sober / vigilant • Adheres to traffic rules • Uses available safety systems (e.g., side/rear mirrors, lights as appropriate to conditions)	• Proper loading and securing of loads • Uses available safety systems (e.g., seat belts and helmets)
Vehicle	• Safe-drivable condition (e.g., good tires, brakes, steering) • Not sized/designed to encourage overloading	• No passenger compartment intrusion • Seat belts available in all seating positions
Infrastructure	• Good surface condition (e.g., dry, even, unbroken) • Proper signage/warnings (e.g., curves, mergers) • Sufficient shoulder width • Good layout / traffic flow • Visibility not obstructed	• No rigid barrier without proper impact attenuators • "Forgiving" features on roadside and median where needed (e.g., steep slope or drop-off)

Accident causation: baseline

For accident avoidance, an ideal condition as a starting point for examining the "human factor" influences is defined as the occupant/cyclist/pedestrian is sober and alert, obeys road regulations and has properly used the available safety systems (mirrors, etc.), as outlined in Table 2. Any variation from this ideal is noted in the causal analysis. A vehicle is defined as ideal when the vehicle is in a safe, drivable condition, it has not been designed to encourage overloading (e.g., more interior or cargo space than vehicle can safely manage when loaded to actual capacity) and it offers provisions for securely fastening loads. Road conditions are considered ideal when the road section is in good condition and has proper signage, sufficient shoulder widths, intuitive road layout and function (for turns, merging, etc.), and good visibility. If any of these ideal conditions are not met, the failure is recorded.

Injury causation: baseline

For injury avoidance, an ideal human condition exists when occupants/cyclists/pedestrians have properly used the available safety systems (seat belts, helmets, etc.), the vehicle is not overloaded (includes passenger loads) and any non-human loads are properly fastened. Ideal vehicle conditions exist when the vehicle has seat belts available for all its seating positions and suffers no passenger compartment intrusion in the accident. Ideal road conditions exist when there are no rigid barriers (including trees) or other dangerous features, such as steep drop offs, rocky outcrops, etc., alongside the roadway or median. If rigid barriers/dangerous conditions do exist, they should be mitigated by impact attenuators or by structures that can afford sufficient protection to keep vehicles safely on the road while still being forgiving enough to avoid creating even more dangerous impact situations than the ones they are protecting against.

Example: baseline applied

As an example of how this works, consider Case 2 from Table 1. In this instance, the contributing factors that led to the accident are human factors alone: driver sleepy and not vigilant (just as in Case 1). However, the contributing factors that led to the fatal injuries are more involved:

- Human - Driver not belted
- Vehicle - Passenger compartment intrusion
- Infrastructure - Absence of impact attenuators before a rigid barrier

Each accident in this study was analyzed against the accident and injury baselines in a fashion similar to that shown in Table 1. The factors were then ranked. For accident causation, this ranking is based on the number of accidents a factor has influenced. For injury causation, the ranking is based on the number of injury occurrences that specific factor has influenced.

Study area

The Mumbai–Pune Expressway is a 94-kilometer, controlled-access highway that connects Mumbai, the commercial capital of India, to the neighboring city of Pune, an educational and information technology hub of India. It is a six-lane roadway with a speed limit of 80 km/h along most of its stretch. Two-wheelers, three-wheelers and pedestrians are not permitted to use most parts of the expressway and non-motorized vehicles are not permitted for the whole stretch. Common vehicle types plying the expressway are cars, trucks and buses.

Data analysis

The methodology study consisted of analysis of contributing factors for 214 accidents (irrespective of injury) that occurred on the Mumbai–Pune Expressway over 12 consecutive months. A second analysis was conducted for those 68 accidents that resulted in a fatal or serious injury.

Injury severity definitions

Figure 1 shows the distribution of accidents by the highest level of injury (severity) sustained by any involved party. The definitions for each level of severity are as follows:

Fatal Injury:	An accident involving at least one fatality. Any victim who dies within 30 days of the accident as a result of the injuries due to the accident is counted as a fatality.
Serious Injury:	An accident with no fatalities, but with at least one or more victims hospitalized for more than 24 hours.
Minor Injury:	An accident in which victims suffer minor injuries which are treated on-scene (first aid) or in a hospital as an outpatient.
No Injury:	An accident in which no injuries are sustained by any of the involved persons. Usually only vehicle damage occurs as a result of the accident.

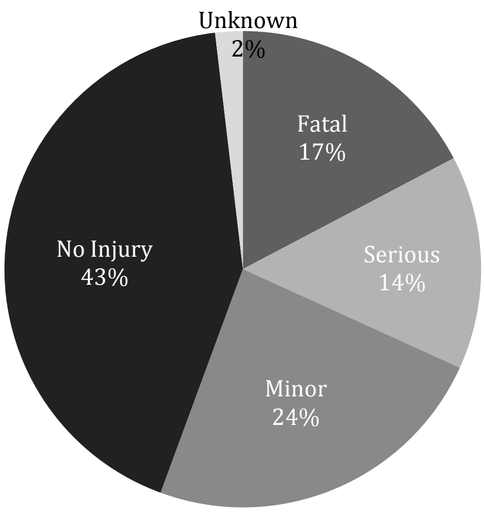

Figure 1. Distribution of accidents by highest injury severity

Factors influencing occurrence of accidents (214 accidents)

A distribution by contributing factors (human/vehicle/infrastructure) for the accidents analyzed is shown in the Venn diagram presented as Figure 2. This diagram shows that human factors alone (57%) had the highest influence on the occurrence of accidents, followed by the combination of human and infrastructure factors (22.5%) and vehicle factors alone (16.5%).

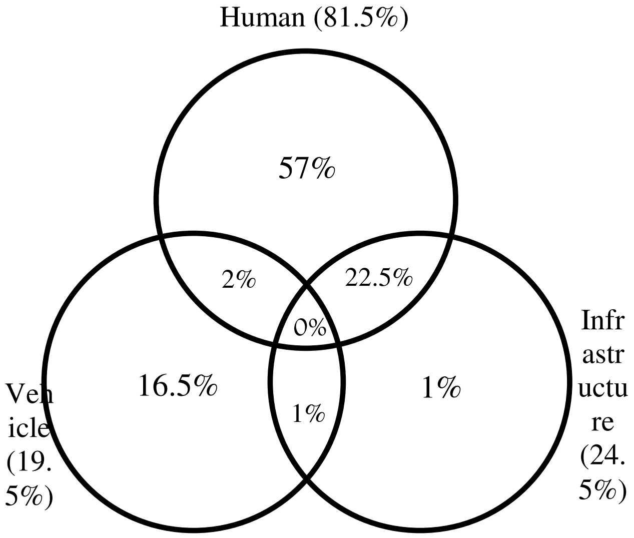

Figure 2. Distribution of accidents by contributing factors influencing accident occurrence

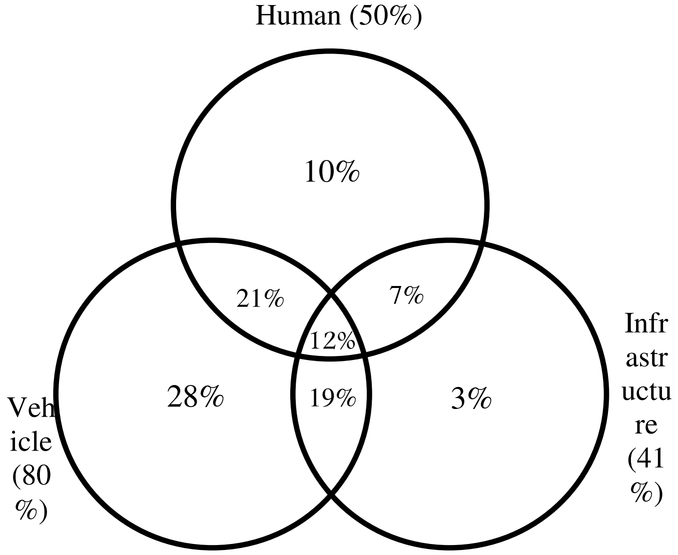

Figure 3. Distribution of fatal/serious injury accidents by contributing factors influencing injury occurrence

Factors influencing occurrence of injuries (68 fatal/serious accidents)

Of the 214 accidents, 68 accidents involved fatal or serious injury to at least one occupant or pedestrian. The distribution by contributing factors (human/vehicle/infrastructure) is shown in the Venn diagram presented as Figure 3. This diagram shows that vehicle factors alone (28%) had the greatest influence on a fatal/serious injury outcome, followed by a combination of human and vehicle factors (21%) and combination of vehicle and infrastructure factors (19%).

When the overlapping combinations are considered, infrastructure factors, which were not so pronounced as a stand-alone (showing only a 3% influence) become more evident (41%).

FINDINGS

The focus of this paper is on the application of a new methodology modified for India, and the findings presented here are offered as demonstration of types of results obtained using this new methodology. For more details on the findings themselves, see the *Mumbai–Pune Expressway Road Accident Study* [5].

Accident occurrence

Accident causal factors were analyzed using the new methodology for all 214 accidents, as described under Methodology. The findings are presented by contributing factor type (human, vehicle, or infrastructure). *Please note that more than one factor can influence an accident; hence, the sum of percentage influence may not be equal to sum of factors influencing accidents.*

Human factors

Table 3 shows the top five contributing human factors that influenced accidents. Speeding and fatigue are the main contributors. Other contributing factors include following too closely (4%), parked vehicle on road (4%), wrong usage of lanes (3%), parked vehicle off road (2%), overtaking from left of vehicle (2%), illegal road usage (2%), driving under the influence of alcohol or drugs (1%) and dangerous pedestrian behavior on roadway (1%).

Table 3. Contributing human factors influencing accident occurrence

Contributing human factors (Accident occurrence)	**Number of accidents**	**% Influenced**
Driver Sleep / Fatigue *(50 Trucks, 12 Cars, 1 Minitruck)*	63	29
Speeding – Excessive speed for conditions *(21 Cars, 12 Trucks, 1 Minitruck, 1 Bus)*	35	16
Speeding - Exceeding speed limit *(28 Cars, 1 Truck, 1 Minitruck, 1 Bus)*	31	14
Improper lane change *(11 Trucks, 5 Cars, 1 Bus)*	17	8
Driving too slow for conditions *(13 Trucks, 2 Cars)*	15	7

Vehicle factors

Table 4 shows the top five contributing vehicle factors that influenced accidents. "Other defect" was also listed as a contributing vehicle factor, with an influence in 1% of accidents. Clearly, though, this category is dominated by brake fade, followed by tire burst.

Table 4. Contributing vehicle factors influencing accident occurrence

Contributing vehicle factors (Accident occurrence)	**Number of accidents**	**% Influenced**
Brake fade *(24 Trucks)*	24	11
Tire burst *(7 Cars, 2 Buses, 2 Trucks)*	11	5
Steering defect *(3 Trucks)*	3	1
Suspension defect *(2 Trucks)*	2	1
Overloading	1	0.5

Infrastructure factors

Table 5 gives the top five contributing infrastructure factors that influenced accidents, with the top four showing fairly equal weight. Other factors include improper gap-in-median (1%), vision obstruction because of plantation (0.5%) and uphill gradient (0.5%). The top five factors together contribute to about 32% of all accidents occurring on Mumbai–Pune Expressway.

Table 5. Contributing infrastructure factors influencing accident occurrence

Contributing infrastructure factors (Accident occurrence)	**Number of accidents**	**% Influenced**
Poor road markings/signage *(11 Trucks, 8 Cars)*	19	9
Narrow shoulder *(13 Cars, 3 Trucks, 1 Bus)*	17	8
Sharp curvature *(10 Trucks, 5 Cars)*	15	7
Inadequate warning about accident/parked vehicle *(11 Trucks, 2 Cars, 2 Buses)*	15	7
No shoulder	3	1

The factor "inadequate warning" was judged to be a failure of the Infrastructure/Accident ideal condition of "proper signage", although it could also fall under a Human/Accident category, depending on the circumstances. See discussion under Limitations/Refinements.

Fatal/serious injury occurrence

Injury causal factors were analyzed using the new methodology for the 68 fatal/serious injury accidents. The findings are presented below. *Please note that more than one factor can influence injury; hence, the sum of percentage influence may not be equal to sum of factors influencing injuries.*

Human factors

Table 6 shows the contributing human factors that influenced fatal or serious injury outcomes. As can be seen, failure to use a seat belt was the single largest human factor influencing injury.

Table 6. Contributing human factors influencing fatal/serious injury occurrence

Contributing human factors (Injury occurrence)	**Number of accidents**	**% Influenced**
Seat belt not used *(26 Cars, 4 Trucks, 1 Minitruck)*	31	46
Overloading of occupants (number of occupants > seating capacity) *(3 Cars, 1 Truck)*	4	6
Occupants in cargo area	1	1
Other	1	1

Vehicle factors

As Table 7 shows, passenger compartment intrusion causing injury occurred in 27 cars and 21 trucks. The breakdown across the four collision types seen for the cars was as follows: 37% were object impacts, 26% were rollovers, 22% were collisions with trucks, and 15% were collisions were cars. For the trucks that involved injuries from passenger compartment intrusion, the collision types and percentages were as follows: 53% were collisions with trucks, 20% were rollovers, 14% were cargo intrusions, and 14% were object impacts.

Table 7. Contributing vehicle factors influencing fatal/serious injury occurrence

Contributing vehicle factors (Injury occurrence)	**Number of accidents**	**% Influenced**
Passenger Compartment Intrusion – Other *(20 Cars, 19 Trucks , 1 Minitruck, 1 Bus)*	41	60
Seatbelts not available/usable *(10 Trucks, 1 Bus)*	11	16
Passenger Compartment Intrusion – Underride / Override *(7 Cars, 2 Trucks)*	9	13
Pedestrian Impact / Run over	4	6
Unsecured Cargo *(3 Trucks)*	3	4

Infrastructure factors

The largest percentages of infrastructure influences on fatal/serious injury involved object impacts, as shown in Table 8. Most of the objects encountered along the expressway are manmade structures located on the roadside or median. On the expressway, these objects included concrete barriers/walls (27%), guard rails (18%), flower pots (14%), bridge walls (14%), overhead bridge pillars (14%), sign posts, curb stones, etc. Flower pots and curb stones may look harmless, but in the event of an impact, these can be quite devastating to the car and its occupants. Natural objects can be just as deadly; trees accounted for 14% of object impacts on the expressway. Also, as noted in the previous paragraph, a lot of passenger compartment intrusions, which significantly reduce occupant safety, have been caused by collisions with these objects.

Table 8. Contributing infrastructure factors influencing fatal/serious injury occurrence

Contributing infrastructure factors (Injury occurrence)	**Number of accidents**	**% Influenced**
Object impact - roadside/median - manmade structures *(17 cars, 1 truck, 1 minitruck)*	19	28%
Roadside - Steep slope/Drop off *(5 trucks, 3 cars)*	8	12%
Object impact - roadside - trees/plantations	3	4%
Object impact – Other	2	3%

The expressway also includes numerous sections with bridges over canals and mountain regions with steep drop offs. It has been noted that adequate barriers are not provided to prevent vehicles from tipping over and plummeting down slopes or into hillsides. Figure 4 presents one such example of an inadequate barrier on a hillside.

Figure 4. Cliffside barrier breached in a crash

DISCUSSION

Comparison to standard approach

The results of the new methodology show that human factors are not the only significant contributors to crashes or injury on Indian roads. While the main contributing factors leading to accidents on the expressway (Table 9) during the study period were, in fact, shown to be heavily weighted to human error, infrastructure was found to be a factor in nearly one fourth of all the accidents analyzed, and vehicle problems were a factor in nearly a fifth. This could be unique to infrastructure, vehicle maintenance, and lack of enforcement issues that exist in developing countries.

Table 9. Main contributing factors leading to accidents
(Based on 214 Accidents on the Mumbai–Pune Expressway)

Human (81.5%)	Vehicle (19.5%)	Infrastructure (24.5%)
• Speeding (30%) • Driver Sleep/Fatigue (29%) • Lane changing (8%)	• Brake fade in trucks (11%) • Tire bursts (5%)	• Poor road markings/signage (9%) • Narrow or no shoulders (8%) • Sharp curvature (7%) • Inadequate warning of accident / broken down vehicles (7%)

The findings are even more striking for injury causes. Table 10 is a summary of the main factors contributing to fatal/serious injuries in the expressway during the study period. In this case, vehicle factors contributed to injuries in 80% of the fatal/serious injury crashes analyzed, with passenger compartment intrusion occurring in 73% of these accidents. Again, lack of safety standards and regulatory requirements contribute significantly to these accidents and injuries.

Table 10. Main contributing factors leading to fatal/serious injuries
(Based on 68 Fatal Serious Accidents on the Mumbai–Pune Expressway)

Human (50%)	Vehicle (80%)	Infrastructure (41%)
• Seat belt not used (46%) • Overloading (6%)	• Passenger compartment intrusion (73%) • Seat belts not available / usable (16%)	• Object impacts with roadside and median manmade structures (28%) • Roadside steep slopes / drop offs (12%)

Limitations/Refinements

The methodology for India is in its infancy, and will be expanded with more data in the future. Probably the greatest opportunity for refinement is in the baseline “ideals” used. For example, the factor “inadequate warning” of a crash or breakdown was judged to be an infrastructure failure, per the Infrastructure/Accident ideal of “proper signage”. This is under the theory that, especially along expressways, there should be a patrolling team which cordons off the vehicles and accident site with appropriate warning signs and devices. However, it could also be considered failure of a Human/Accident ideal condition *if* one existed, that covered vehicle occupants’ failure to place safety triangles or flares on the road. In this case, interpretation plus lack of a fitting “ideal condition” for accident avoidance under human factors, pushed all such events into the Infrastructure/Accident category.

Similarly, some "ideal" conditions would benefit from being stated as more specific subsets. For example, the ideal infrastructure conditions for accident causation could be clarified to specifically include "road is smooth and free of potholes or significant defect" and "road is free of contaminants (water, gravel, oil, etc.) affecting traction/steering", etc. versus the current, broadly phrased "good surface condition". Ideal vehicle conditions regarding accident avoidance could specify such safety systems as working headlights and taillights (and a related human factor noting lights should be "on" in low visibility conditions); at present, condition of lights is not routinely or reliably recorded in most accident reports, although where information on poor condition of the lighting system is available, it is coded in the model.

As the codes listed in Appendices A and B show, there are many categories that overlap. In the absence of an existing baseline for Indian road conditions (such as the standard rating systems available for the SRA model), the ideals set forth in Table 2 are a first attempt to pull some of these categories together in an intuitive way. The goal is to form a broadly-stated standard designed to make coding easier and subsequent analyses more meaningful.

CONCLUSIONS

The use of the new methodology to examine crashes on the Mumbai–Pune Expressway shed light on the influences of vehicles and infrastructure. Human factors alone (57%) were found to have the highest influence on the occurrence of accidents, followed by the combination of human and infrastructure factors (22.5%) and vehicle factors alone (16.5%). Vehicle factors alone (28%) were found to have the greatest influence on a fatal/serious injury outcome, followed by a combination of human and vehicle factors (21%) and combination of vehicle and infrastructure factors (19%).

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APPENDIX A: CONTRIBUTING FACTORS FOR ACCIDENT

HUMAN – 1000		
Code	**Category**	**Description**
1100	**Driver - Fitness To Drive**	
	1101	Driver - Alcohol
	1102	Driver - Other Stimulation substances - drugs, medication
	1103	Driver - Sleep/Fatigue/Drowsiness
	1104	Driver - Illness or disability - mental or physical
	1147	Driver - Other

HUMAN – 1000			
1150	**Pedestrian - Fitness To Walk**		
		1151	Pedestrian - Alcohol
		1197	Pedestrian - Other
1200	**Speed**		
		1201	Speeding - Exceeding speed limit
		1202	Speeding - Excessive speed for conditions
		1203	Speeding - Speed limit unknown
		1204	Driving too slow for conditions
		1205	Parked - vehicle on road (full or partial)
		1206	Parked - vehicle off the road
		1207	Parked - vehicle due to traffic
		1297	Other
1300	**Distraction - Driver**		
		1301	Driver using mobile phone
		1302	Driver distraction inside vehicle
		1303	Driver distraction outside vehicle
		1304	Driver Inattention
		1347	Other
1350	**Distraction - Pedestrian**		
		1351	Pedestrian using mobile phone
		1354	Pedestrian inattention
		1397	Other
1500	**Driver Behaviour**		
		1501	Use of wrong lane (includes overtaking in undivided roads)
		1502	Illegal road usage (includes travelling in the wrong direction)
		1503	Violation of Right of Way
		1504	Following too closely
		1505	Overtaking on left side of vehicle
		1506	Changing lanes / Turning suddenly or without indication
		1547	Other
1550	**Pedestrian Behaviour**		
		1551	Pedestrian - Dangerous behaviour on roadway
		1597	Other
		9999	Unknown

VEHICLE - 2000			
Code	**Category**		**Description**
2100	**Vehicle Defect**		
		2101	Defective - Tires
		2102	Defective - Brakes
		2103	Defective - Steering
		2104	Defective - Suspension
		2197	Defective - Other
2200	**Vehicle Misuse**		
		2201	Overloading - goods
		2202	Goods not secured properly

VEHICLE - 2000		
	2203	Overloading - people
	2297	Other
2400	**Vision Obstruction**	
	2401	Due to vehicle interiors
	2497	Other

INFRASTRUCTURE - 3000		
Code	**Category**	**Description**
3100	**Road Surface Defects**	
	3101	Defective road surface
	3102	Slippery road surface
	3103	Deposits on road surface (oil, mud, fluids, etc.)
	3197	Other
3200	**Road Design**	
	3201	Sharp Curvature
	3202	Bridge
	3203	Shoulder - Narrow
	3204	Shoulder - None
	3205	Uphill gradient
	3247	Other
3250	**Pedestrian Infrastructure**	
	3251	Poor pedestrian infrastructure - Crossing
	3252	Poor pedestrian infrastructure - Walking alongside
	3253	Public Bus stop
	3297	Other
3300	**Road Information**	
	3301	Poor road marking/signage
	3302	Poor street lighting
	3303	Poor object conspicuity
	3304	Inadequate warning about accident / parked vehicle
	3397	Other
3400	**Vision Obstruction**	
	3401	Parked vehicles
	3402	Manmade objects
	3403	Trees/Plantation
	3404	Hill Crest
	3405	Road Curvature
	3497	Other
3500	**Road Traffic Flow**	
	3501	Undivided
	3502	Gap-in-median
	3503	Intersection
	3504	Work zone
	3597	Other

APPENDIX B: CONTRIBUTING FACTORS FOR INJURY

HUMAN - 1000		
Code	**Category**	**Description**
1600	**Safety System Use**	
	1601	Seat belt not used
	1602	Helmet not used
	1603	Occupants in cargo area
	1604	Overloading of occupants
	1697	Other
1800	**Lifesaving Skills**	
	1801	Improper accident/breakdown management
	1802	Lack of first-aid skills
	1803	Improper evacuation of occupants
	1897	Other

VEHICLE - 2000		
Code	**Category**	**Description**
2600	**Crash Protection**	
	2601	Seatbelts not available/usable
	2602	Runover (for Pedestrian, M2W riders)
	2603	Passenger Compartment Intrusion - Underride/Override
	2604	Passenger Compartment Intrusion - Other
	2605	Retrofitted fuel kit
	2606	Protruding/oversized cargo
	2607	Unsecured Cargo
	2697	Other
2800	**Vehicle**	
	2801	Entrapment
	2802	Fire
	2897	Other

INFRASTRUCTURE - 3000		
Code	**Category**	**Description**
3600	**Road Furniture**	
	3601	Object impact - road side - trees/plantation
	3602	Object impact - road side - manmade structures
	3603	Object impact - Other
	3604	Road Side - Steep slope/Drop off
	3697	Other
3800	**Medical Response**	
	3801	EMS availability
	3802	Distance to hospital
	3897	Other

In-depth study of accidents involving light goods vehicles

T Serre*, C Perrin*, M Dubois-Lounis*, C Naude*

*IFSTTAR, Department for Transport Health and Safety, Laboratory of accident mechanism analysis, 304 chemin de la Croix Blanche, 13300 Salon de Provence, France

Abstract - This work aimed for getting the main features of accidents involving Light Goods Vehicles (LGV), using accident cases collected in the In-Depth Accidents Studies built up at IFSTTAR-LMA (France), in order to analyse thoroughly the proceedings of these accidents and identify the major factors for the different types of LGV. This work was based on the analysis of 88 accident cases involving LGV with a Maximum Authorised Mass inferior to 3.5 tonnes. In particular kinematics reconstruction of these accidents were performed to calculate the average impact speeds and to better understand the compatibility problems between LGV and antagonist vehicles. Specific features have been reviewed to pick up problems concerning safety, maintenance, loading, LGV design: general conditions of the accident, vehicle features, and passive safety. The main results of this study are presented in this paper.

INTRODUCTION

The words “Light Goods Vehicles” (LGV) are commonly used to refer to a vehicle belonging to a company, conceived and fitted out to carry goods, with only two or three places in the front, and especially for a professional use. The term of commercial vehicle can be also considered. For this type of vehicle, the French Highway Code retains the French word “camionnette” (van) with the following definition: motor vehicle with at least four wheels, designed to goods transportation, with a total authorised loaded weight inferior to 3.5 tonnes [1].

According to the ONISR (French national observatory of the road safety) [2, 3, 4], at the beginning of 2011, 5.8 millions of LGV were in service in France. LGV are more and more present on French roads, since they represented 15.4% of all vehicles in 2010, against 11% in 1985. The number of LGV involved in accidents with injuries, inventoried by the ONISR, lightly increased since 2000 (5780 vehicle in 2000 against 5974 in 2010). In parallel, it is observed on one hand an increase of the number of casualties, and on the other a worsening of the accidents.

The tendency extends in all Europe, even if in the last three years the number of LGV licence numbers decreased [5]. According to this study based on the accidents data of 21 European countries on the last available year, 2006, it is inventoried:

- 10% of all vehicles are LGV,
- 8% of all accidents involve LGV,
- 9% of all fatal accidents involve LGV.

A study completed in UK on accidents involving LGV between 2006 and 2008 pointed out that the occupants of cars are very frequently injured in the accidents involving LGV [6]. Otherwise it was observed that about 75% of deceased occupants of LGV went first through a frontal impact; this situation represents also 69% of gravely injured occupants of LGV. Heavy goods vehicles are the most decisive (40%) in deceases of LGV occupants. Nevertheless it should be noted that 41% of deceases of LGV occupants occurs because of an impact other than vehicle-vehicle: rollovers and obstacles.

Despite these studies it has to be pointed out that knowledge of LGV accidents is to date not enough explored, even though the number of accidents involving this type of vehicles reveals itself to be increasing.

The objective of this work was to identify the major technical features of accidents involving LGV. It focused on:

- The impact speeds of these vehicles,
- The influence of loading in the accident: fixing, tidying up, involvement in injury generation, etc.,

- The influence of the type of LGV: shape, presence of partition between passenger compartment and loading, safety equipment, etc.,
- The question of compatibility between LGV and the other vehicles in order to determine the damage sustained by antagonist vehicles such as [9]: weight ratio, localisation of deformations, injuries, etc.

MATERIAL AND METHODS

In-Depth Accident Studies (IDAS)

This work was mainly based on data collected by In-Depth Accident Studies (IDAS) built up at IFSTTAR Laboratory of accident mechanism analysis [7]. It should be noted that the first objective of this database is to be illustrative of the diversity of the accidents but not necessary statistically representative of all the accidents in France.

The principle of IFSTTAR IDAS is to collect in real time as many information as possible on the three components of the system driver-vehicle-environment. The investigation area is around the town "Salon de Provence" in France. A multidisciplinary team of investigators (a technician and a psychologist) is automatically alerted and takes action at the same time as the emergency service on the scene of the accident. It makes its own collection (material tracks, witness statements) focused on the proceedings of the accident and its circumstances. Collected data concern the involved persons, the vehicles, the road and the environment.

On the scene of accident the priority is to take pictures and films of the final positions of the vehicles, of the tracks on the ground, of the vehicles deformations and every other relevant element that can help to understand the accident. A careful examination of involved vehicles is made to collect the positions of the gear lever, the weight of a possible loading, the presence of a mobile phone…

The whole data collected is structured in check-lists and coded. The medical files (anthropometric measures, statements on lesions, etc.) concerning victims are also colligated in the emergency service of the hospital in Salon de Provence.

A kinematics reconstruction is performed with specific IFSTTAR-LMA software, based on final and impact positions, skid marks, angle of the impact, impact locations on the vehicles, involved persons accounts, victim's injuries… The objective of the reconstruction is to build a spatiotemporal description of the accident proceedings, consistent with the whole data (Figure 1).

The method used requires knowledge in kinematics [8] and is based on the estimation of some parameters such as the energy spent in the vehicle deformation, the decrease in speed of the vehicle depending on the tyre marks on road, etc. Trajectories of vehicles involved are determined according to data collected on the scene of the accident: final positions, marks, estimated positions at impact point, and arrival directions of each vehicle. In general, it is necessary to go back in time and on the trajectory of each vehicle involved with the calculation of simple kinematics sequences (each sequence is associated to a simple kinematics model). The post-crash phase is modelled by a constant speed movement or by a uniformly accelerated movement. The analysis of the collision consists in applying simple mechanical laws: conservation of momentum (two axles) and conservation of energy (kinetic and deformation). The global objective is thus to balance these three simultaneous equations. The study of the pre-crash phase uses exactly the same principles of calculation than the post-crash ones.

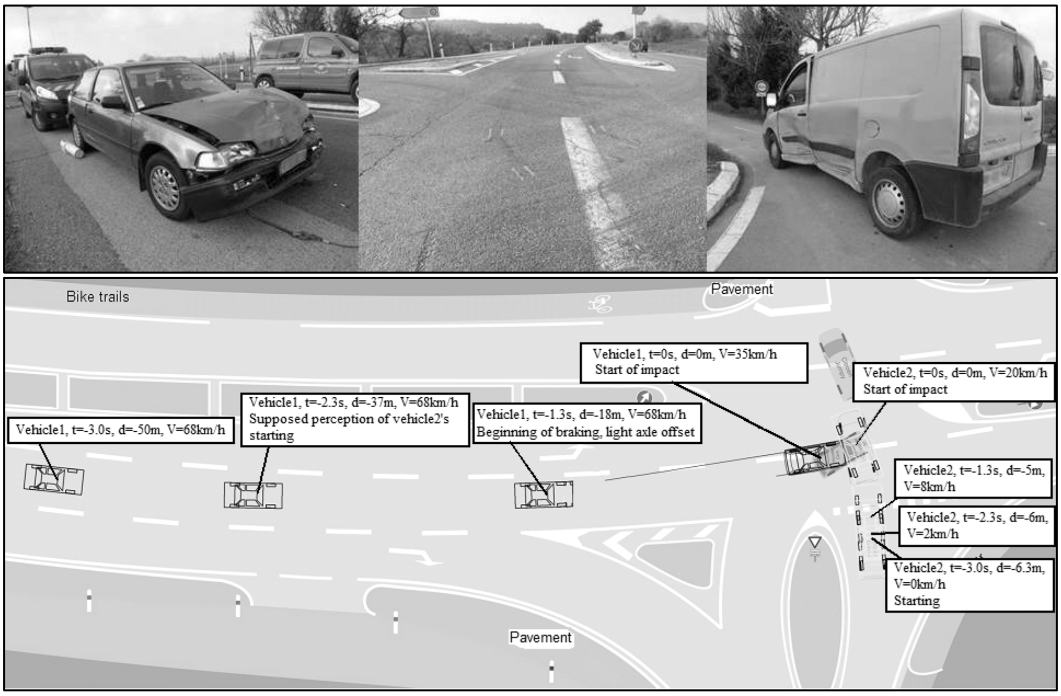

Figure 1. Results of the kinematics reconstruction of an accident, spatiotemporal description of its proceedings

Specific LGV data

The accidents involving at least one LGV were selected in the IDAS database. Types of LGV retained for this work have a Maximum Authorised Mass (MAM) inferior to 3.5 tonnes (ex. delivery van: Peugeot Partner and Renault Master) and are not directly derived from a passenger car, thus not including commercial cars (ex. Peugeot 206 société, Renault Mégane société). In total 88 IDAS accidents involving 90 LGV were selected and analyzed between 1992 and 2012.

A large part of the data was directly extracted from the IDAS coded database which contains more than 600 variables for every accident. However, this study was focused on accidents involving LGV and a new file of specific data coding was elaborated. New variables were created and added to this file as regards safety problems, maintenance, loading, type of design, useful volume, specific layout, etc.

The whole set of data was classified in different sections briefly described below:

- "Identification" in which there are the general conditions of the accident, types of involved persons, and overall severity of injuries, etc.
- "Vehicles" in which there are vehicles equipment, mileage, design type, general state, useful volume, useful load, presence of ABS (Anti-lock braking system), description of essential elements for primary safety, size of tyres, loading index for each wheel (measure and manufacturer specification), etc.
- "Secondary safety" in which there are the number and types of impacts, the variation of speed due to the impact, the presence of airbags, the fixing and storage of loading, its implication in the accident, etc.
- "Drivers" in which there is a description of the driver physical and mental state, in the long, medium and short terms, his socio-professional category, his driving experience, his relation with his vehicle, his perception of the accident proceedings, his declared speed in approach, etc.
- "Passengers" in which there is a description of each passenger: his place in the vehicle, his age, his size, his weight, his use of the protection systems (seat belt, airbag, …), his injuries, etc.

It should be noticed that all the accidents and all the variables do not have the same level of completeness. Some data are missing in some accidents. In the results presented in this paper, the sample size for each analysis is always given.

RESULTS

In order to explicit specific features of light goods vehicles, a detailed description of the LGV sample is given and often compared to the whole IDAS database if necessary.

Type of LGV

Among the 90 LGV vehicles of the sample, 18 have a MAM <1.5T, 24 a MAM between 1.5T and 2.5T, and 48 a MAM>2.5T and <3.5T.

LGV were also classified according to other factors: useful volume and design type (Table 1). Indeed these two criteria vary a lot from one model to another that can affect for example the inherent aggressiveness of the LGV (height and stiffness of the chassis, position of the centre of gravity, etc.). Thus it is necessary to distinguish between the LGV based on a tourism car, called here “Goods car”, the other design types of auto-porter with a big size called “Van” and “Big van”, and at last the “chassis-cab” LGV with a big compartment or a dump. The table 1 presents the distribution of the LGV sample according to their useful volume and their design type.

	Categories of useful volume in m^3	Number of vehicles	Percentage %
Goods car 	Less than 6	42	47
Van  **Big van** 	Between 6 and 12	25	28
Chassis-cab with compartment 	More than 12	12	13
Chassis-cab with dump 	Type Pick-Up/Dump	11	12
	Total	90	100

Table 1. Distribution of the LGV sample according to the useful volume and the design type

The average age of the LGV at the time of accident is 6 years old: quite recent in relation to the whole national LGV fleet that is 9.3 years old [2]. It denies the hypothesis of the damaged LGV being the elder ones of the national LGV fleet.

Manoeuvre at the origin of the accident

The manoeuvre at the origin of the accident is considered as the driving situation that leaded to the accident, apart from the configuration of the impact itself. Figure 2 shows that the LGV are less subject to loss of control in a straight line, 14% against 19% for all IDAS accidents, and also in bend 13% against 22%. On the contrary LGV are more involved in intersection accidents: 39% against 27% for the whole IDAS.

It seems to highlight that the LGV drivers have difficulties to perceive other road users due to numerous internal obstacles to visibility. It has also been noted that on 4 accidents involving a LGV and a pedestrian, the LGV was going backward in 2 cases. Yet there is no radar detection in the back of the vehicle in the sample. This kind of ADAS (Advanced Driver Assistance System) that is becoming more and more common on passenger cars could be a great element to equip consistently the LGV to avoid this kind of accident in backward configuration.

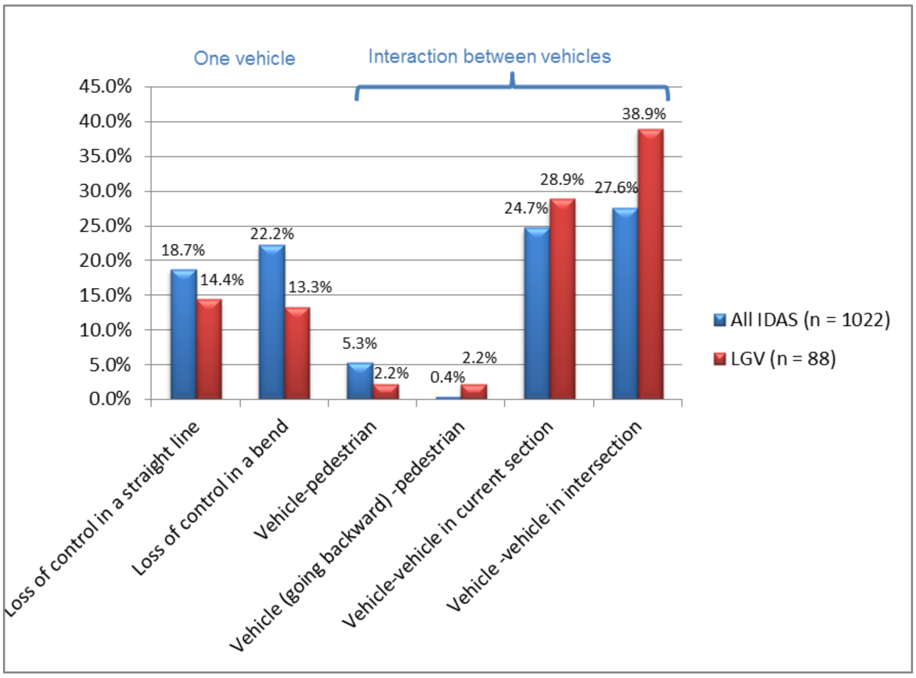

Figure 2. Distribution of the manoeuvres at the origin of the accidents

Type of impact

Figure 3 presents the distribution of the types of impact for the 90 LGV. The most frequent configuration is the frontal impact (53%), then the lateral impact (20%), and at last the rear impact (13%).

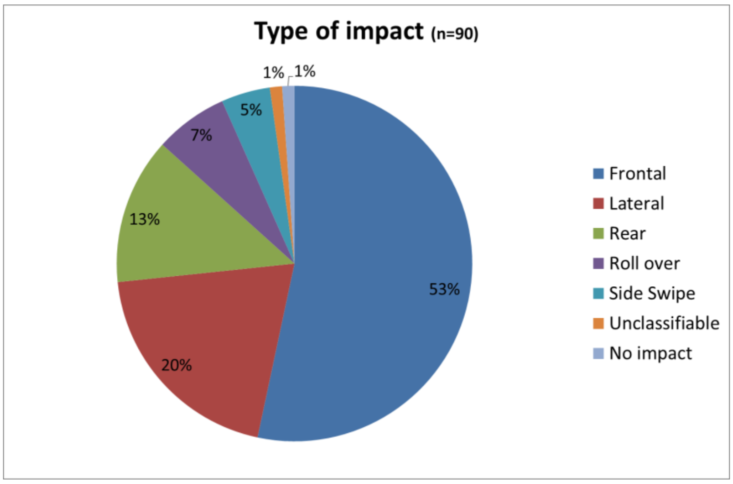

Figure 3. Configuration of the first impact for the LGV

Obstacle

This part considers the obstacle hit by the LGV during the impact phase, and not the type of antagonist vehicle or pedestrian with whom there was an interaction leading to the accident. It should be noted that LGV have less impacts against tourism cars (43% against 48% for all IDAS), but more impacts against 2 wheels-motorised (22% against 9%), as can be seen at Figure 4. Again it could be a problem of internal obstacles to visibility leading to worse perception of vulnerable road users, which have a lower visible size than cars.

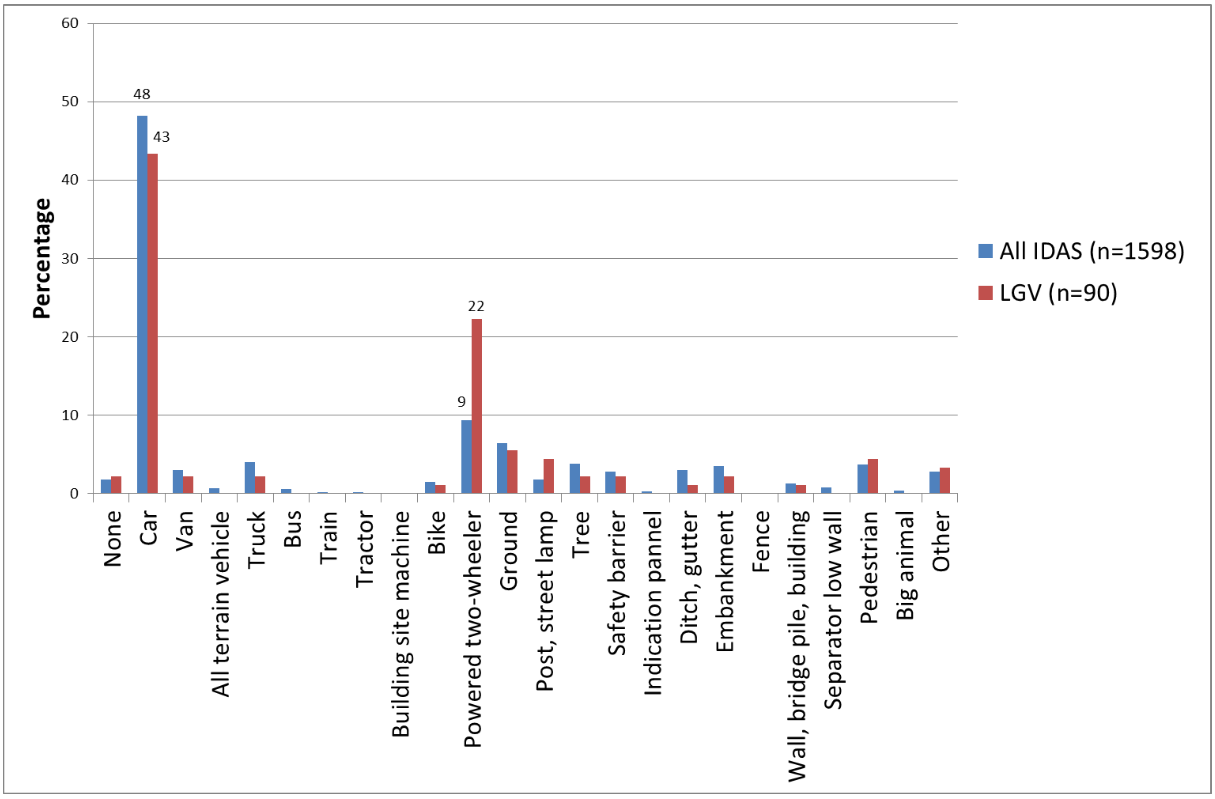

Figure 4. Distribution of accidents according to the impacted obstacle

Impact Speeds

The sample presented here includes 45 accidents of LGV. The cases where the LGV go backward are stationed, or have a speed under 10 km/h (moving of, slow manoeuvre, U-turn, entry/exit of parking, etc.) were suppressed. The considered speed is the one just before the impact. These impact speeds were calculated thanks to the kinematics reconstructions carried out in the IDAS.

Figure 5 presents the distributions of impact speeds for all IDAS and for LGV accidents. The average impact speed for the LGV accidents outside urban area is 44 km/h (n=36, median 44 km/h, standard deviation 21 km/h) and 35 km/h in urban area (n=9, median 38 km/h, standard deviation 15 km/h). The average impact speed of all IDAS cases outside urban area is higher, 59 km/h (n=546, median 55 km/h, standard deviation 26 km/h) and quite similar in urban area, 37 km/h (n=181, median 35 km/h, standard deviation 17 km/h).

To sum up, there is almost no difference in impact speeds in urban area between LGV and the reference all IDAS, whereas outside urban area impact speeds are lower for LGV than for all IDAS.

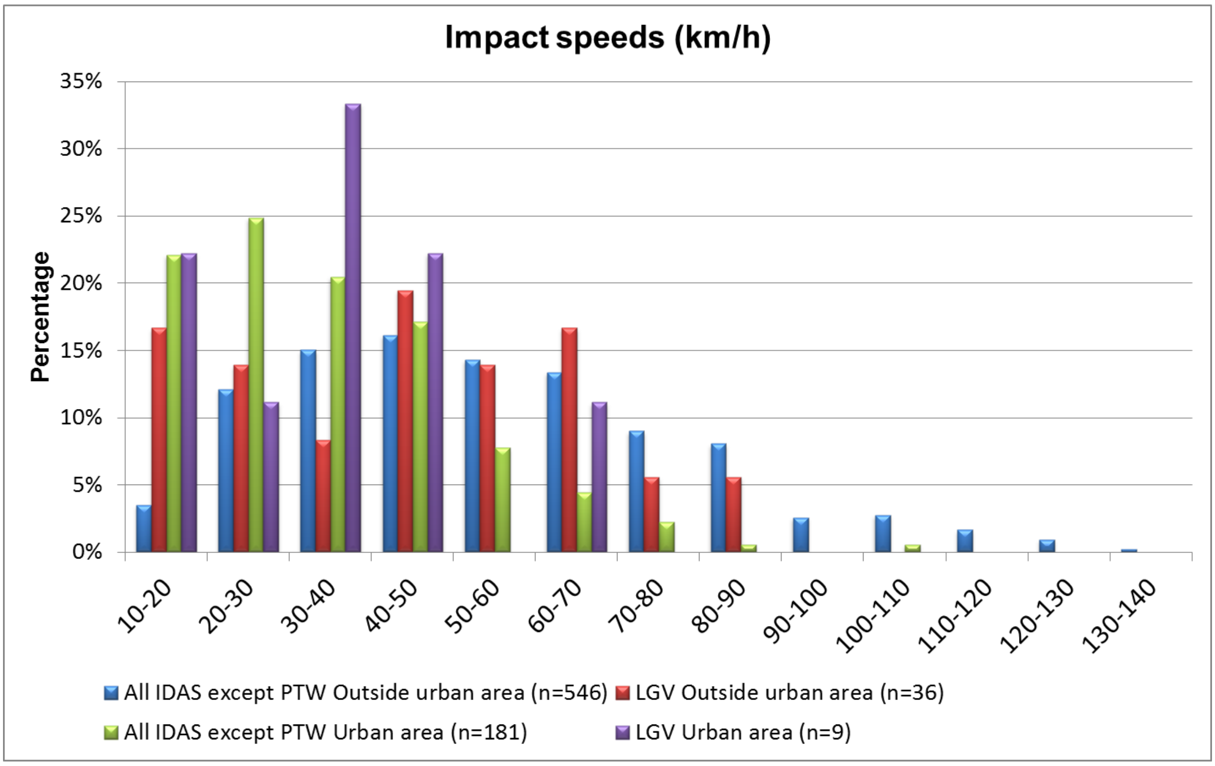

Figure 5. Distribution of accidents according to the impact speeds

Tyres

Concerning the state of the tyres, the following rules have been taken into account:

- There is a pressure default when the measure on one or several tyres differs by more than 0.3 bars from the recommended specification of the manufacturer.
- There is a wear default when the sculptures depth is lower than 1.6 mm (regular wear, significant crackle, hernia, etc.),
- The loading index of a tyre corresponds to the maximal loading that a tyre can support at the maximal speed given by the speed code. It is given by the manufacturer. If the loading index is lower than the one specified by the LGV manufacturer, there is a default.

Figure 6 presents the frequency of appearance of these defaults.

These results lead to the fact that the maintenance of LGV is insufficient concerning tyres. Indeed more than one third of LGV presents an under-inflation problem. Nevertheless few wear defaults are recorded. It could indicate that the regulatory maintenance is well done, but much less the basic maintenance such as the check of tyres pressure. Actually these vehicles are often used by several drivers which can result in negligence in usual maintenance. Moreover, even if the sample is small with 24 cases, 50% of LGV have a loading index lower than the manufacturer recommendation.

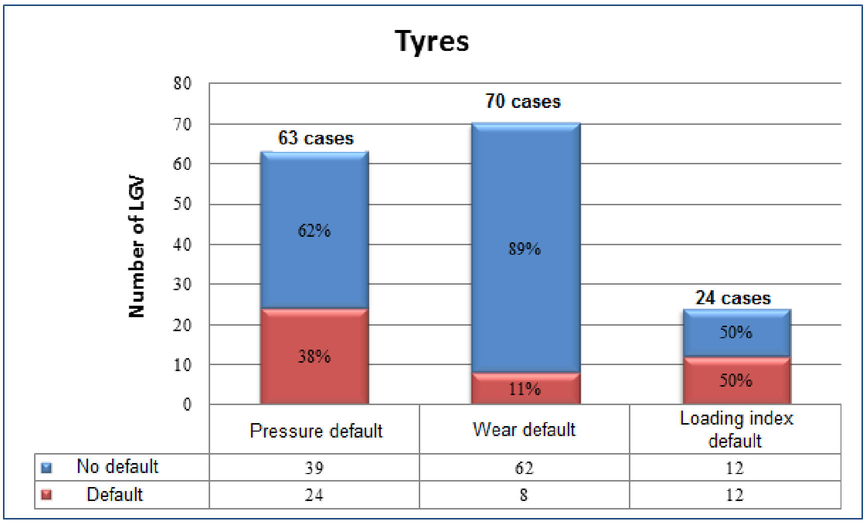

Figure 6. Repartition of tyres defaults

Among the 90 LGV listed, 7 have a tyre technical default which played a role in the proceedings of the accident, one was a blow-out, 4 were pressure defaults, one a wear default, and one a combination of pressure and wear default. It could be useful to encourage manufacturers to equip LGV with tyre pressure sensors as it exists for some passenger cars) in order to prevent this technical problem.

Loading

Most LGV of the sample (77%) have a Maximum Authorised Mass (MAM) higher to 1.5t and lower than 3.5t (Figure 7). Generally the loading restrictions applied to the vehicle are respected. However when these restrictions are overstepped, it is by far. Indeed the 6 vehicles overloaded have an excess between 200 and 500 kg.

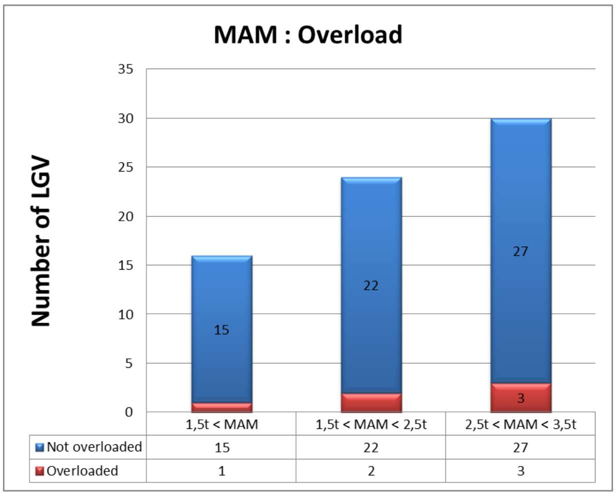

Figure 7. Number of LGV overloaded according to the MAM

Concerning the load thrust, which means when pieces of goods got into the passenger compartment, it has been observed in only 7 cases by 82. But these load thrust had no consequence in terms of injuries on the occupants.

About the presence of a partition between the driver and the load, it has been observed in 56 cases (65%) among 86 LGV for which this information is known. This partition can be a sheet steel or Plexiglas® plate, a grill, a wooden panel, etc. By these 56 cases, 37 have a load not fixed. Deformations of the partition were observed in only 3 cases. In one of these 3 cases the partition gave away on the passenger side. But in this last case, the driver was alone in the vehicle and was not injured, so it had no consequence in term of injury. For all the other accidents the partition was efficient and not damaged.

It is important to notice that on the 56 cases with the presence of a partition, 25 vehicles had no rear visibility at all (that is to say no inside rear-view mirror or back radar) while this type of vehicles is often brought to manoeuvre, especially to go backward.

Safety equipment

Almost a third (36%) of the drivers in LGV accidents did not use their seat belt at the moment of the accident. This result is in accordance with [9]. In comparison the seat belt ratio at front places in the passenger cars involved in an accident is 97.4% [4]. It seems thus necessary to encourage the LGV drivers to wear their seat belt by all available means: sound warning, communication, awareness, control, etc.

Furthermore, the driver airbag is a safety device that can highly reduce the severity of driver injuries. It is nevertheless observed that there is a significant gap between the LGV equipment ratio and other types of vehicles in the IDAS database. Indeed 76% of LGV vehicles are not equipped with driver airbag against 66% for the other vehicles.

This ratio of LGV equipment is improving for several years because it was 24% for the accidents since 1992 and 48% for the accidents of the last ten years (Figure 8).

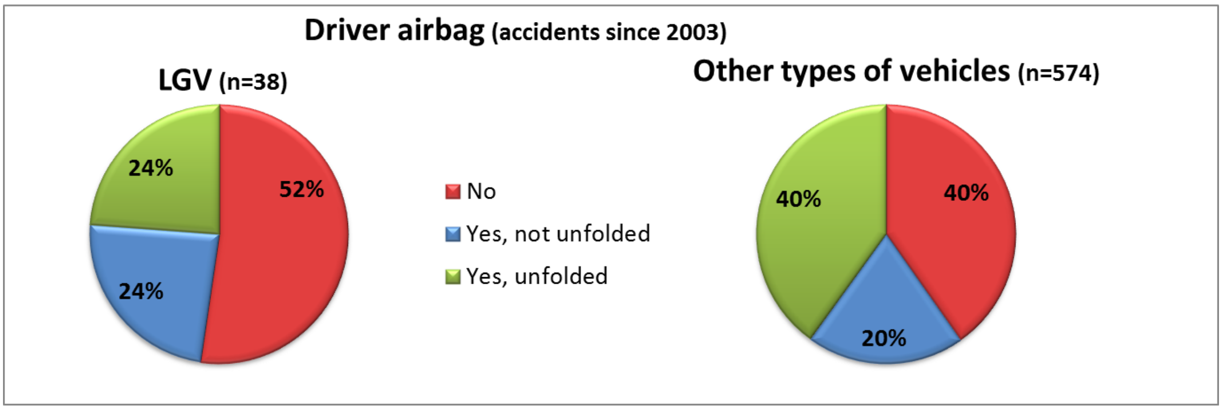

Figure 8. Presence and trigger of the driver airbag (accidents since 2003)

Severity of accidents

By the 88 LGV accidents, 64 involved another vehicle. 175 persons altogether were involved in these 64 accidents: 91 in a LGV and 84 in another vehicle. Almost half of them are unharmed, about 40% are slightly injured, nearly 11% seriously injured and 4 deceased (Figure 9). It can be noticed that there are nearly twice injured and deceased persons in the other vehicles than in LGV, and on the contrary there are twice unharmed persons in LGV than in other vehicles.

These observations seem to show that LGV are more aggressive and raise questions about the compatibility between LGV and other vehicles: mass, stiffness, height, etc.

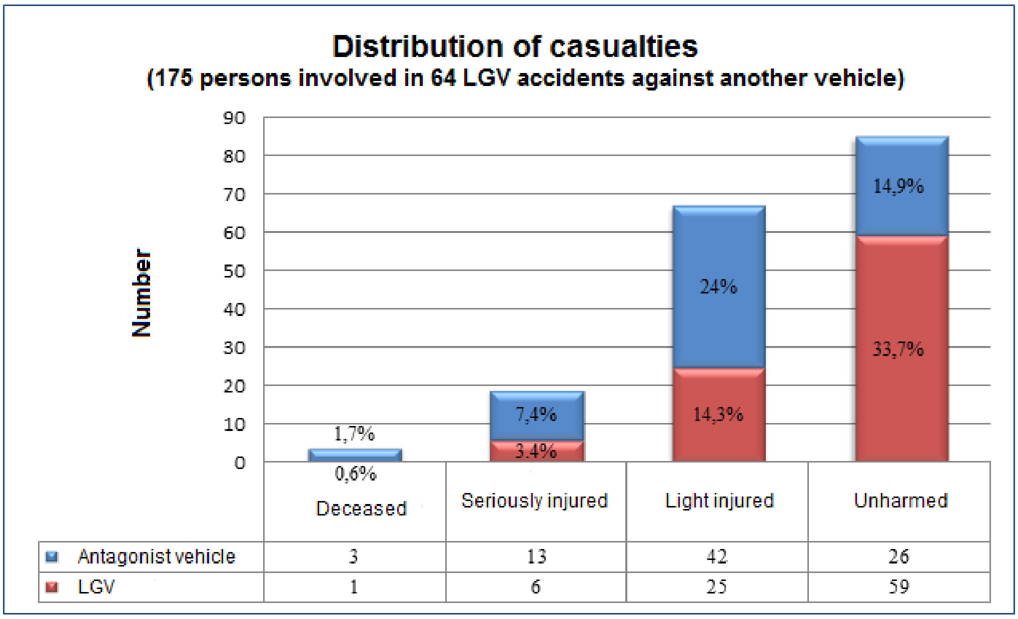

Figure 9. Distribution of the casualties in 64 accidents involving a LGV and another vehicle, according to the type of vehicle

CONCLUSION

The added value of this research work was to provide an in-depth analysis of the proceedings of 88 accidents involving LGV extracted from the In-Depth Accidents Studies (IDAS) of the IFSTTAR-LMA laboratory. Indeed it was about identifying features playing a key role and sometimes distinctive for this type of vehicle. The main results of this study are:

- Half of LGV in the sample are light goods cars (such as Renault Kangoo, Peugeot Partner…).
- LGV seem to be less involved in loss of control and more in accidents in intersection, possibly because of perception problem of the others due to internal obstacle to visibility.
- There were few technical defects and almost only defaults of pressure or loading index on tyres. Therefore checking pressure of tyres should be reinforced as well as the good adaptation to the loading index.
- Load thrust is not decisive in the accident thanks to a partition when present.
- There is a low rate of ADAS for LGV like radar or backup camera even though their rear visibility is very low.
- There is still a low rate of passive safety equipment (Airbag…).
- Few drivers of LGV wear their seat belt. Thus an incentive is necessary by all means: sound alert in the vehicle, communication, raising awareness, control, etc.
- Impact speeds seem equivalent to other vehicles.
- Impacts are mostly frontal for LGV.
- Aggressiveness of LGV appears to raise problem and compatibility with the other vehicles should be better taken into account.

Even though this study is limited in term of representativeness of the LGV involved in road accidents in France, it provides preliminary results that could orientate a following study on a bigger sample. For instance future works based on the analyse of a bigger sample of accidents police reports could let know if the LGV aggressiveness is simply due to a larger mass or to other factors such as differences in stiffness, in height, or in shape, etc.

ACKNOWLEDGEMENTS

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Cyclist-reported habits of helmet usage and differences in riding postures by using helmets

Jänsch, M., Otte, D.

[1] *Accident Research Unit, Hannover Medical School*

Abstract

Within the COST Action TU1101 the working group WG 1 is dealing with acceptance criteria and problems in helmet use while bicycling concerning conspicuity, thermal stress, ventilation deficits and other potential confounding.

To analyze the helmet usage practice of bicyclists in Europe a questionnaire was developed in the scope of working group 1 to collect relevant information by means of a field study. The questionnaire consists of some 66 questions covering the fields of personal data of the cyclist, riding und helmet usage habits, information concerning the helmet model and the sensation of the helmet, as well as information on previous bicycle accidents. A second complementary study is conducted to analyze if the use of a bicycle helmet influences the seating geometry and the posture of cyclists when riding a bicycle and if the if the helmet vertically limits the vision. For this purpose cyclists with and without helmets were photographed in real world situations and relevant geometrical values such as the decline of the torso, the head posture of the upper vertical vision limit due to the helmet were established from the photos.

The interim results of the field studies which were conducted in Germany by the Hannover Medical School are presented in this study. Some 227 questionnaires were filled out, of which 67 participants had used a helmet and 42 of the 227 participants have had a bicycle accident before. For the analysis of the riding position and posture of the cyclist over 40 pictures of riders with a helmet and over 240 pictures of riders without a helmet were measured concerning the seating geometry to describe the influence of using a bicycle helmet.

Some results in summary: From the riders interviewed with the questionnaire only 11% of the city bike riders and 12% of the mountain bike riders always used the helmet, while 38% of the racing bike riders and 88% of the e-bike-riders always used the helmet. The helmet use seems not to change the sensation of safety of cycling compared to the use of a car. The arguments for not wearing a helmet are mostly stated to be the short distance of a trip, high temperatures or carelessness and waste of time. The reasons for using a helmet are stated to be the feeling of safety and being used to using a helmet. Being a role model for others was also stated to be a reason for helmet use. Concerning the sensation of the helmet 9% of the riders reported problems with the field of vision when using a helmet, 57% saw the problem of sweating too much, and 10% reported headaches or other unpleasant symptoms like pressure on the forehead when using the helmet. The analysis of the seating posture from the pictures taken of cyclists revealed that older cyclists generally have a riding position where the handle bar is higher than the seat (0° to 10° incline from seat to handlebar), while younger riders had a higher variance (between -10° decline and 20° incline). Further, elderly riders and riders with helmets seem to have a more upright position of the upper body when cycling. The vertical vision limit due to the helmet is determined by the front rim of the helmet (mostly the sun shade). Typical values here range from 0° (horizontal line from the eye to the sun shade) to 75° upwards, in which elderly riders tend to have a slightly higher vertical vision limit possibly due to the helmet being worn more towards the face.

The European Project COST Action TU 1101 is an expert network focusing on improving bicycle traffic safety with a special focus on helmets [1]. As a partner of this project the Hannover Medical School (MHH) is participating in the two field studies conducted by the working group 1 of this project. One field study aims to collect information on the habits of helmet usage of cyclists by means of a questionnaire, while the other field study aims at identifying if the use of a bicycle helmet influences the seating geometry and the posture of cyclists when riding a bicycle and if the helmet vertically limits the vision towards important traffic details. As the field studies are ongoing in the different countries this study will present some interim results of data collected in Germany at the Hanover Medical School.

Questionnaire on helmet usage

For the COST Action TU1101 a field study was conducted using a questionnaire to investigate the helmet using habits of bicycle riders in different EU-countries.

The questionnaire was developed among the COST partners and resulted in a paper questionnaire including questions from the fields of personal data, helmet data, sensation of the helmet, helmet usage as well as information a possible former bicycle accident. Due to the fact that some questions of the questionnaire were relevant for different respondents and some were not relevant (e.g. Helmet comfort is not relevant for a bicyclist without a helmet), the data collection was conducted by an interview instead of asking the interviewee to fill out the questionnaire by himself.

A representative investigation of bicycle riders was not required, however the location and the time of interviewing riders was distributed to different locations and times. In Germany Interviews were conducted at colleges/universities which lead to a significant portion of younger bicyclists and interviews were also conducted at supermarket during normal work hours which lead to a higher portion of elderly bicyclists. As an alternative a survey was also conducted at a public event for bicycle riders which on one hand lead to a rather mixed portion of respondents concerning the age, however this time the helmet wearing rate seemed to be higher. In general the focus of the chosen interviewees was set to riders using a helmet to gain as much possible information on the helmet topics of the questionnaire. Thus this study is not suitable to evaluate helmet wearing rates.

Some 227 questionnaires were filled out, of which 67 participants had used a helmet and 42 of the 227 participants have had a bicycle accident before.

The interim analysis of the data collected by the questionnaires shows that slightly more men were interviewed than women (129 men; 98 women) and that on significant difference in helmet wearing shares between men and women is found in the group (29% of the women and 30% of the men wore a helmet).

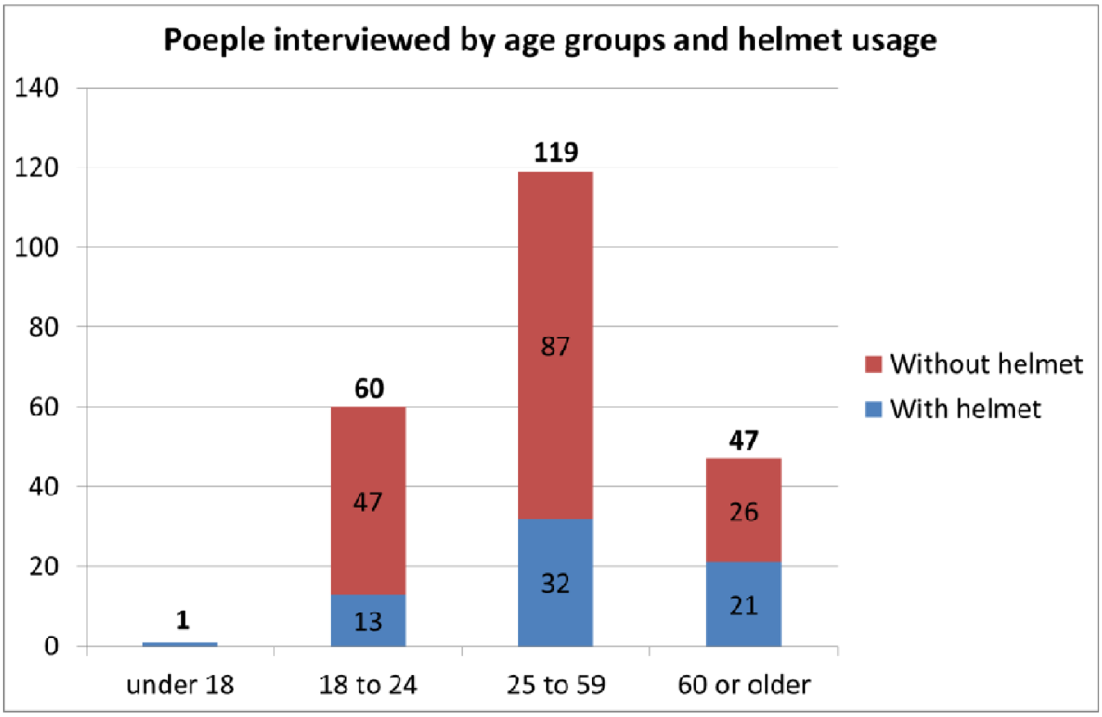


Figure 1: Distribution of age groups of people interviewed with the questionnaire.

The distribution of the age of the interviewed people on different groups (Figure 1) shows that the majority of riders can be found in the age group between 25 and 59 years of age, while older riders 60 years or older more frequently had worn a helmet in 21 of 47 cases (45%).

In 151 cases the type of bicycle used by the rider was known of which the majority had used a "city-bike", with 68% (102 cases). Only about 17% of the interviewed riders had used a mountain bike and 9% had used a racing bike. A total of 8 riders using E-bikes were interviews which accounts for a share of about 5%.

In the scope of the questions concerning the personal data and helmet usage habits the riders were asked how often they usually wear a bicycle helmet. Some differences were found in the answers here depending on the type of bicycle used, see Figure 2. While the riders of city bikes and of mountain bikes in the great majority of cases answered that they rarely or never use a helmet (75% of city bikes; 81% of mountain bikes), the riders of racing bikes seem to be have a higher desire for safety: "Only" 54% answered that they rarely or never use a helmet while some 38% stated that they always use a helmet. Of the 8 riders of pedelecs/E-bikes seven stated that they always use a helmet and only one rider claimed never to use a helmet. It will be interesting to see if this high helmet wearing rate was only coincidence because a closed group of 7 elderly riders was interviewed or if this result is reproduced in the data collected in future and by other counties.

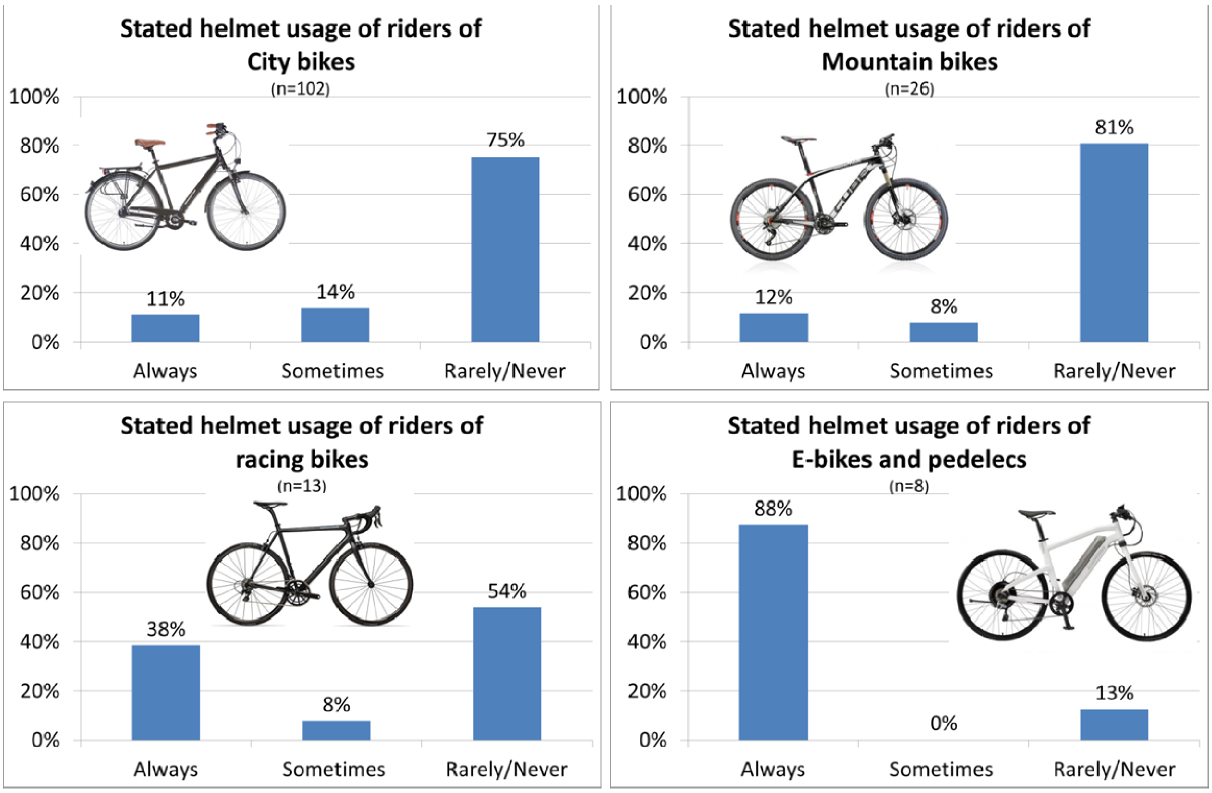


Figure 2: Stated helmets usage rates of riders of different types of bicycles.

Further the safety sensation when riding bicycle was asked: The riders were asked if they felt that cycling was much safer, a little safer, about the same, a little more dangerous or much more dangerous compared to driving a car and compared to walking. Here in general most riders think that cycling is more dangerous than walking or driving a car (Figure 3). When looking at the differences between the group of riders that had used a helmet and the group that had not used a helmet, there seems to be a slight tendency towards a the feeling that riding a bicycle is more dangerous among those that had used a helmet: 74% of the helmet users thought that cycling is more dangerous than driving a car, compared to only 67% of the riders without a helmet and 88% of the helmet users thought that cycling is more dangerous than walking, compared to only 78% of the riders without a helmet.

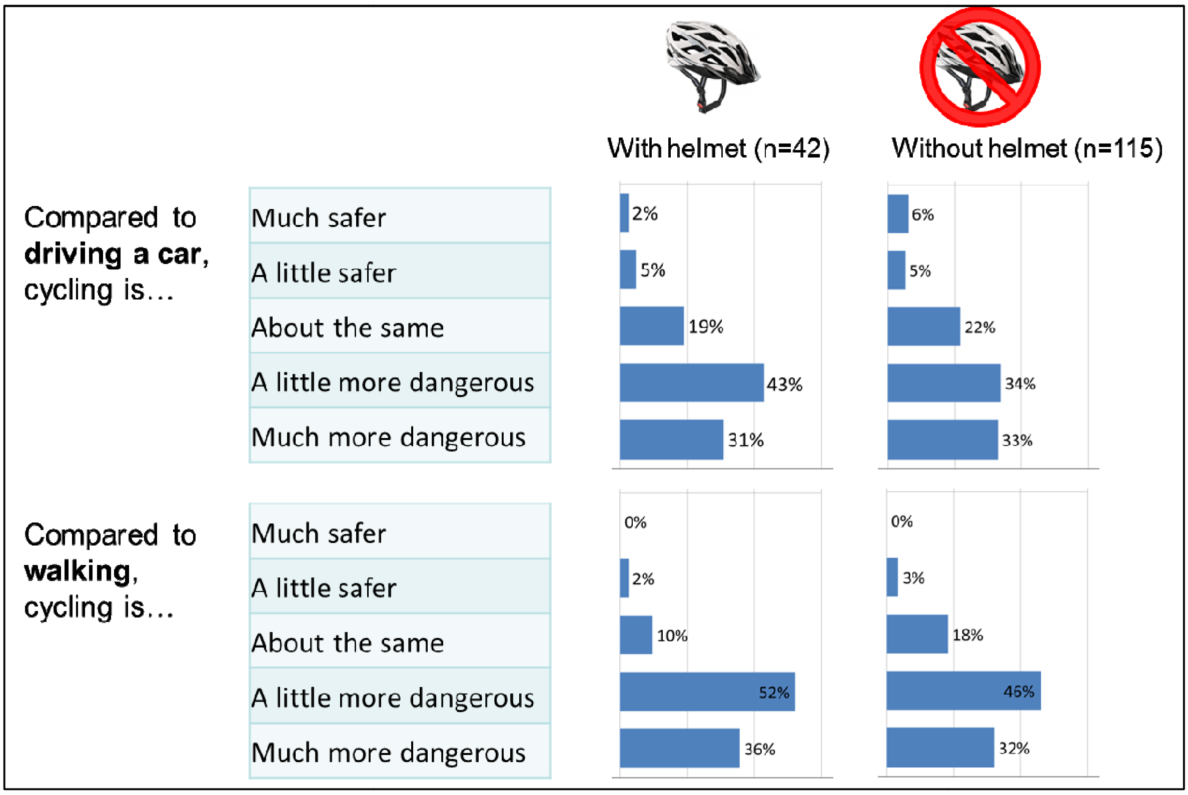


Figure 3: Safety sensation of riding a bicycle compared to driving a car or walking.

To identify the reasons of riders for using a helmet or respectively for not using a helmet, a list of possible reasons was given and the interviewed people were asked to rate the relevance of each of these reasons with: 0 - never a reason; 1 – rarely a reason; 2 – often a reason; 3 – mostly a reason; 4 – always a reason. Figure 4 shows the mean values of the ratings of these reasons for using a helmet and for not using a helmet.

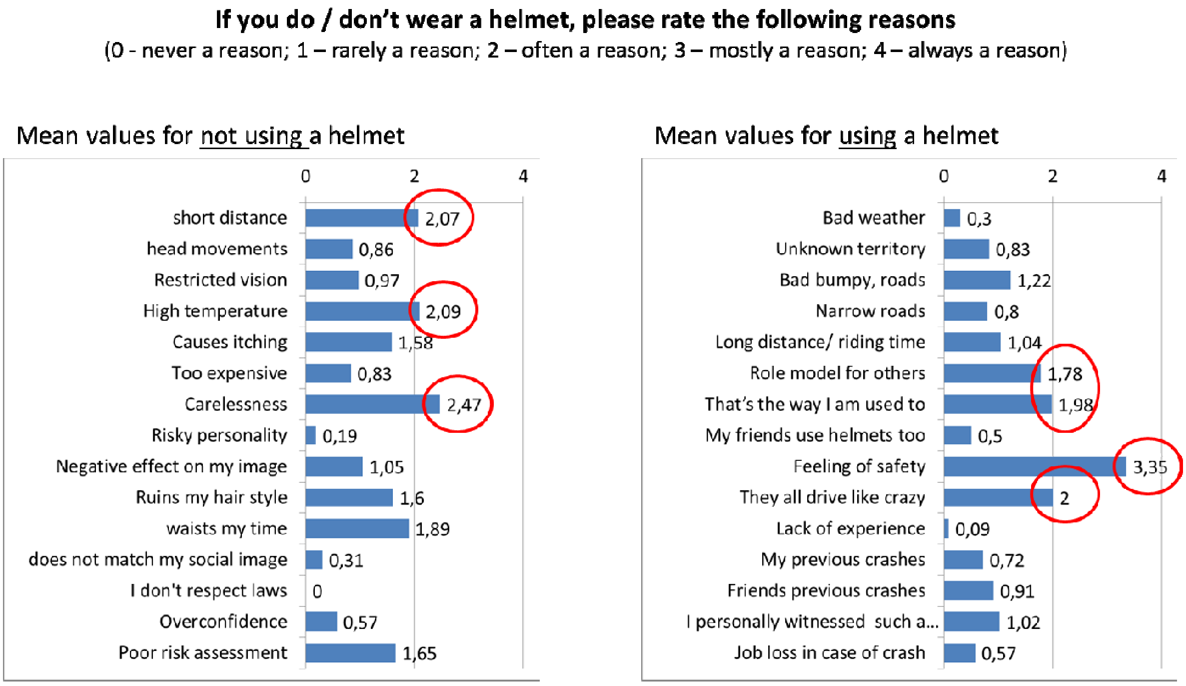


Figure 4: Reasons for using a helmet and respectively for not using a helmet

Among the most common reasons for not wearing a helmet were reasons like "I will only go a short distance", "it's too warm (high temperature)" and mostly carelessness with a mean value of 2.47. Riders that at least sometimes used a helmet answered that the reason for using the helmet was mostly the feeling of safety (mean value of 3.35). Other reasons with high scores for using a helmet are that the other traffic participants are felt to represent a danger - "they all drive like crazy" (mean value of 2), being used to wearing a helmet as a reason for wearing a helmet with 1.98 and being a role model for others e.g. children (mean value 1.78).

One reason for not wearing a helmet which was often mentioned but which was not anticipated and thus was not found on the list of reasons was: "when I reach my destination I have to carry around my helmet".

The information on the sensation of using a bicycle helmet and whether there are any constraints when using the helmet was also collected with the questionnaire. Here none of the 67 interviewed riders with a helmet stated that they had hearing problems when using a helmet. However 6 riders (9%) stated that they feel that the helmet does narrow their field of vision. From the 63 riders that responded to the question if using the helmet makes them sweat more, 34 (57%) half responded with yes. Asked about headaches or other unpleasant symptoms after using a bicycle helmet 6 riders (10%) said that they do sometimes feel unpleasant symptoms: 4 stated that they sometimes have a headache, one rider felt a pressure on the forehead and one lady responded that she gets a dry and itchy skin on the head from using a helmet.

The interviewed riders were ultimately asked about previous bicycle accidents. From the 42 riders that had a bicycle-accident before some 34 indicated the type of accident they had had (Figure 5). With 70% the majority of riders stated that they had a single-vehicle accident (e.g. a fall due to a driving error). A collision with a car had been the case in 21% of the accidents while collisions with other types of road users or with fixed objects had rarely occurred (only 3% each).

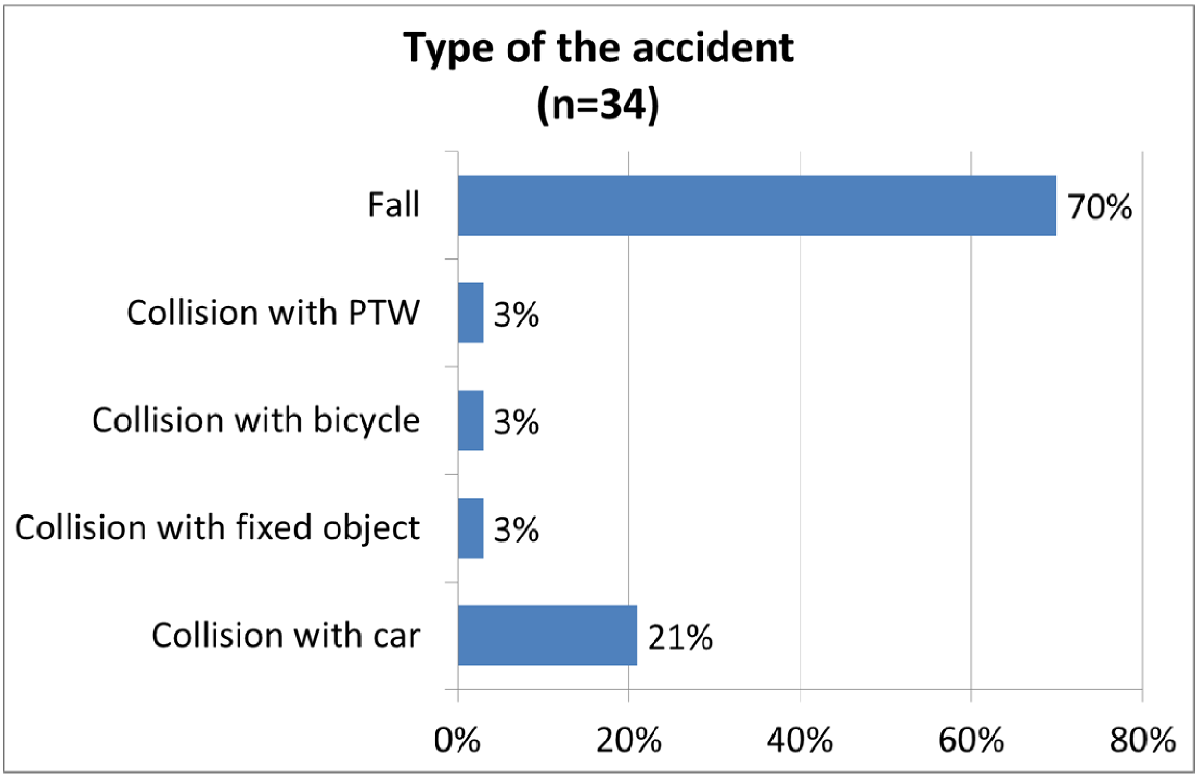


Figure 5: Type of bicycle accident of 34 interviewed riders that had had a bicycle accident before.

If the respondents had been wearing a helmet at the time of the accident and if the helmet had an impact during the accident, they were additionally asked where the main impact zone on the helmet was.

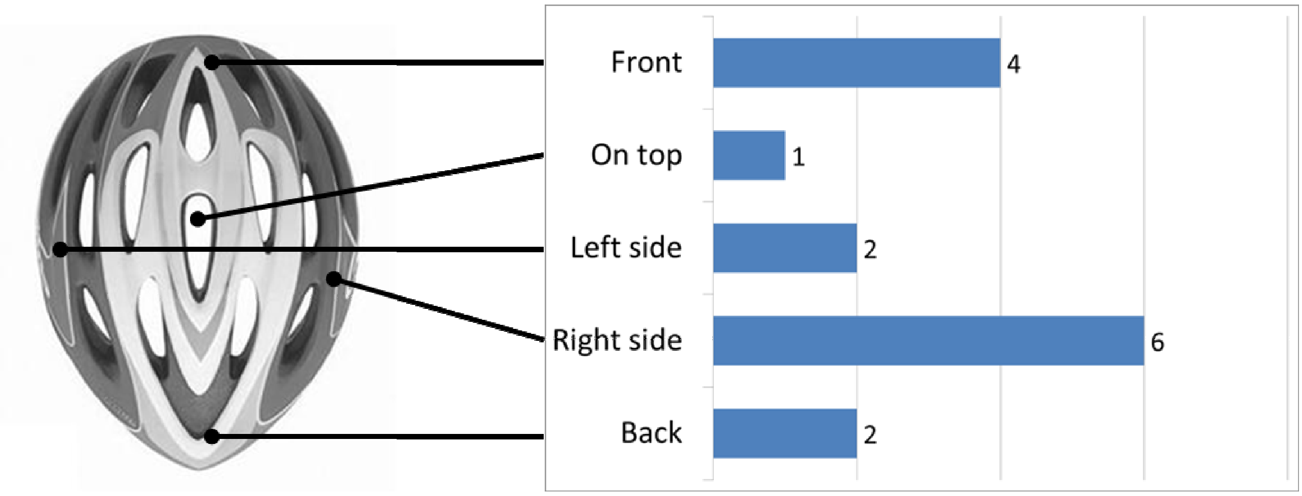


Figure 6: Main impact zones on the helmet during a bicycle accident from 15 respondents.

As displayed in Figure 6, 4 of the 15 riders stated that their helmet had an impact at the front while only twice an impact at the back of the helmet and only once an impact at the top of the helmet were reported. Mostly however the impact had occurred at the sides of the helmet: 8 riders stated that the impact was either on the left side (2 riders) or on the right side (6 riders).

Influence of the bicycle helmet usage on the posture of cyclists

Next to the above mentioned study via questionnaire the COST Action TU1101 also conducts a study to identify if the usage of a helmet has an influence on the seating posture of a cyclist such as a more upright seating position or head posture. This is done in different EU-countries by taking pictures of cyclist and comparing the seating geometry of riders with a helmet and riders without a helmet.

Bicycle riders which did and did not use a cycle helmet were photographed while riding the bicycle in a real world (non fictional) situation. The picture was taken anonymously from a large distance using a telephoto lens without the perception of the bicyclist. To be able to measure the seating posture correctly it is necessary to take pictures of cyclists riding rectangular to the photo axis (taking a picture exactly from the side of the cyclist).

To define the seating geometry the sitting decline SD (angle of the cyclist's torso) and the angle between the handlebar and the seat HS were established for both riders with and without helmets (see Figure 7). Subsequently the inclination of the line of the visual limit VL was investigated from pictures of riders using a helmet and the head posture HP was measured by the inclination of the line from the ear to the eye (see Figure 8).

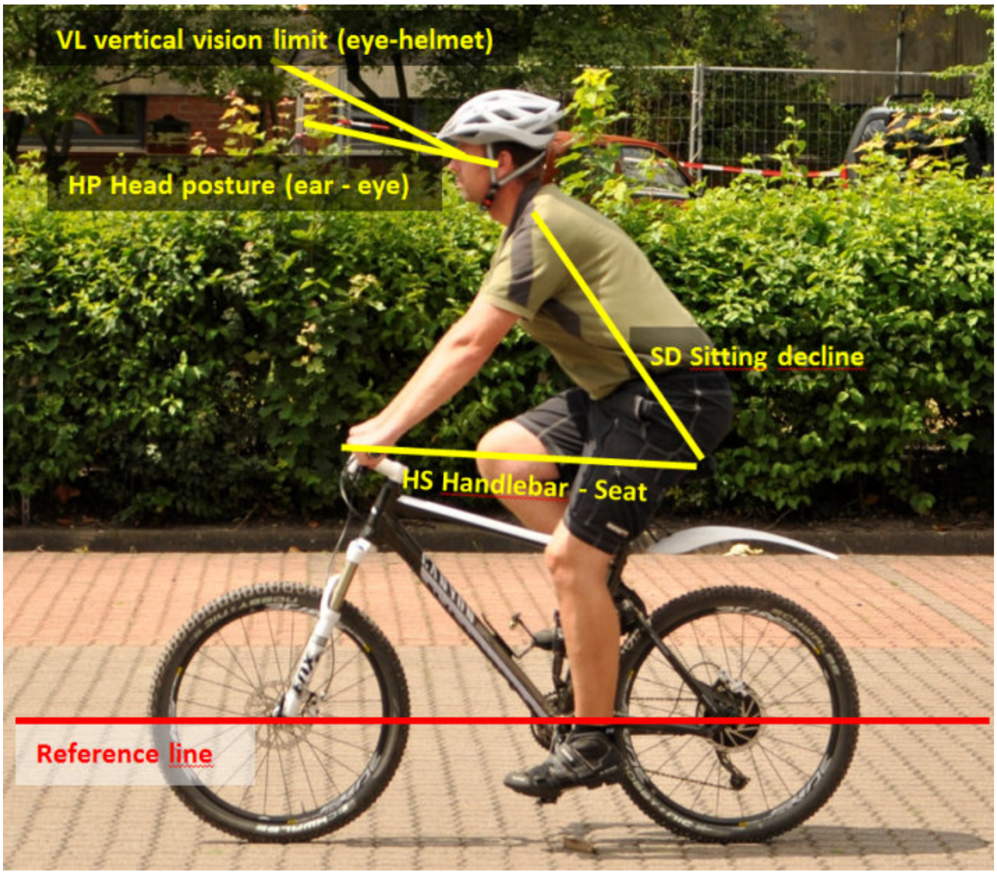


Figure 7: Establishment of angels relevant for seating geometry and vision limits

Figure 8: Establishment of the head posture angle by measuring the inclination of the line from the ear to the eye.

As the pictures taken could be askew a horizontal reference line was established in a first step which was used as a base line to measure the angles (see red line in Figure 7). A possible reference for this purpose is the line between the two axles of the bicycle, but could also be a horizontal line of building if e.g. the axles of the bicycle wheels are not visible on the photo.

In Germany the pictures were mostly taken during normal working hours at a “bicycle highway” which represents a major bicycle path separated from other traffic and which connects an urban district with the city centre. From the 290 pictures which were taken of cyclists some 42 riders had been wearing a helmet. Again this share of helmet wearers cannot be called representative because the focus of this study was set to collecting as many cyclists with a helmet as possible.

The interim analysis of the cycle geometry shows that slightly more pictures of male riders with a helmet were taken than of female riders with a helmet (23 men; 19 women) and that in the group of riders without a helmet the amount of male riders (157) was also higher than the amount of female riders (91). It has to be noted that the gender and the age group of the rider was estimated from the pictures.

The distribution of the riders with and without a helmet on the different age groups is shown in Figure 9. The riders that had been wearing a helmet were clearly younger than the riders that had not been wearing a helmet: About 69% of the riders with helmet were from the age group of 19-40 years, while only about 43% of the riders without a helmet were of this age. Accordingly there were less riders with helmet found in the age groups of 41-65 years (21%) and 66 years or older (10%) than riders without a helmet (groups of 41-65 years: 40% and 66 years or older: 16%).

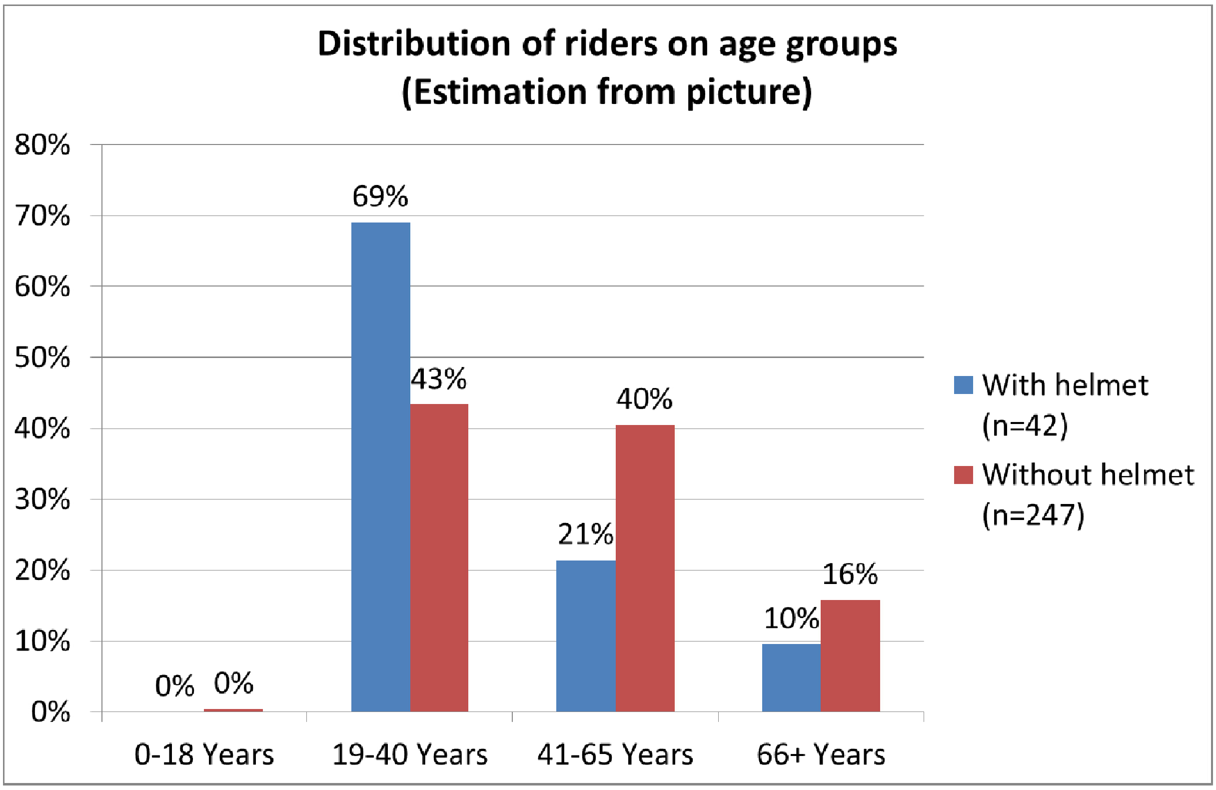


Figure 9: Distribution of photographed riders on age groups

The analysis of the inclination between handle bar and seat was done by calculating the cumulative frequency of the riders with a helmet and comparing that to those not wearing a helmet for different age groups, see Figure 10 and Figure 11. Over 10% of the riders (independent of the helmet usage) had a negative inclination which correlates with a seat position being higher than the handle bar. For riders where the seat is below the handle bar (>0°) there seems to be a slight bias towards higher handle bars and lower seats in the group of riders not wearing a helmet (red line in Figure 10). When comparing the two age groups "40 years or younger" and "41 years or older" there seems to be a slight tendency towards higher inclination angles with the older riders (Figure 11, red line) which means that they tend to sit more upright. It has to be stated however, that due to relatively low case numbers up to now no significant differences can be identified. It can be expected that the final analysis or the full study with cases from other countries will provide more significant results.

A similar slight influence of the helmet usage and the riders age can also be found on the sitting decline (which describes the inclination of the riders back; Figure 12, Figure 13). This correlation was expected as the sitting decline is dependent of the height of the handle bar relative to the riders seat. The red line in Figure 12 displays the cumulative frequency of the sitting decline of riders without a helmet. Here about half of the riders without a helmet have a decline of the back of just under 70° while that of the riders with a helmet is a few degrees lower. The influence of the age, Figure 13, on the sitting decline seems to be less pronounced than the influence of the helmet usage but is still visible.

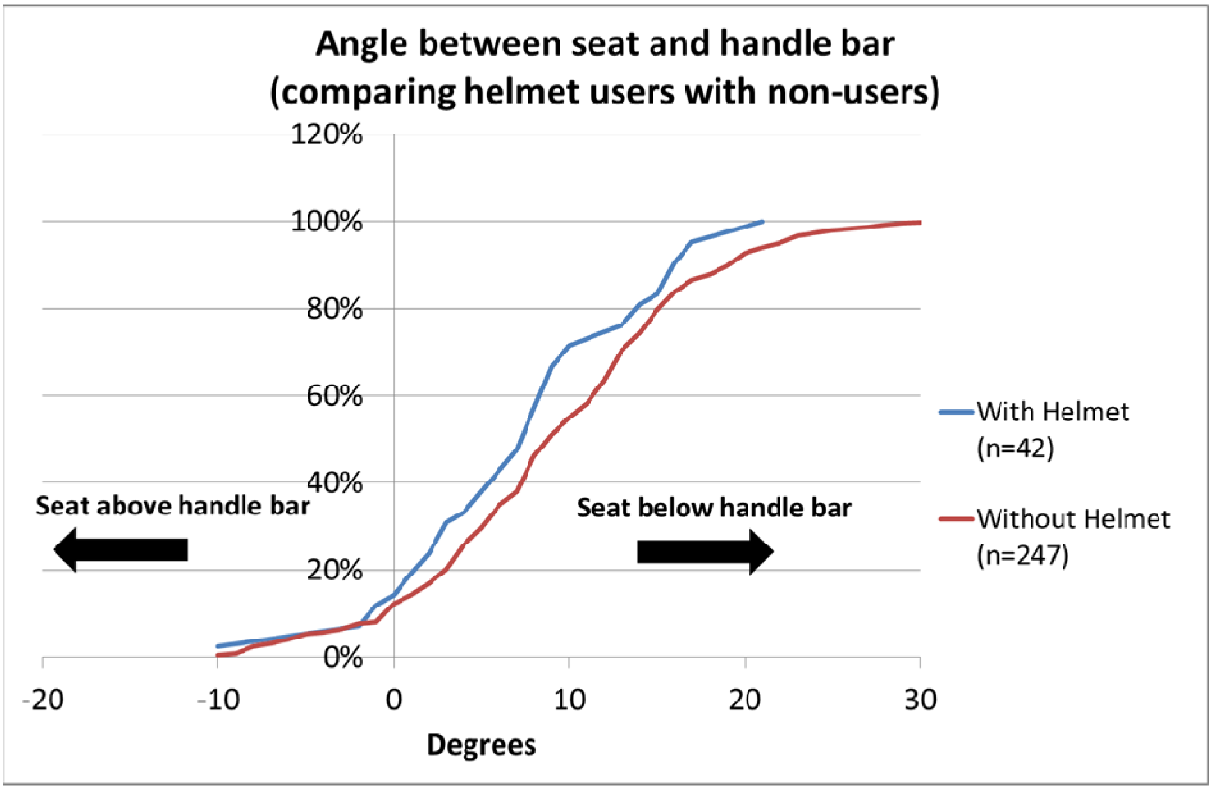


Figure 10: Angle between handle bar and seat (cumulative frequency), comparing riders with and without a helmet.

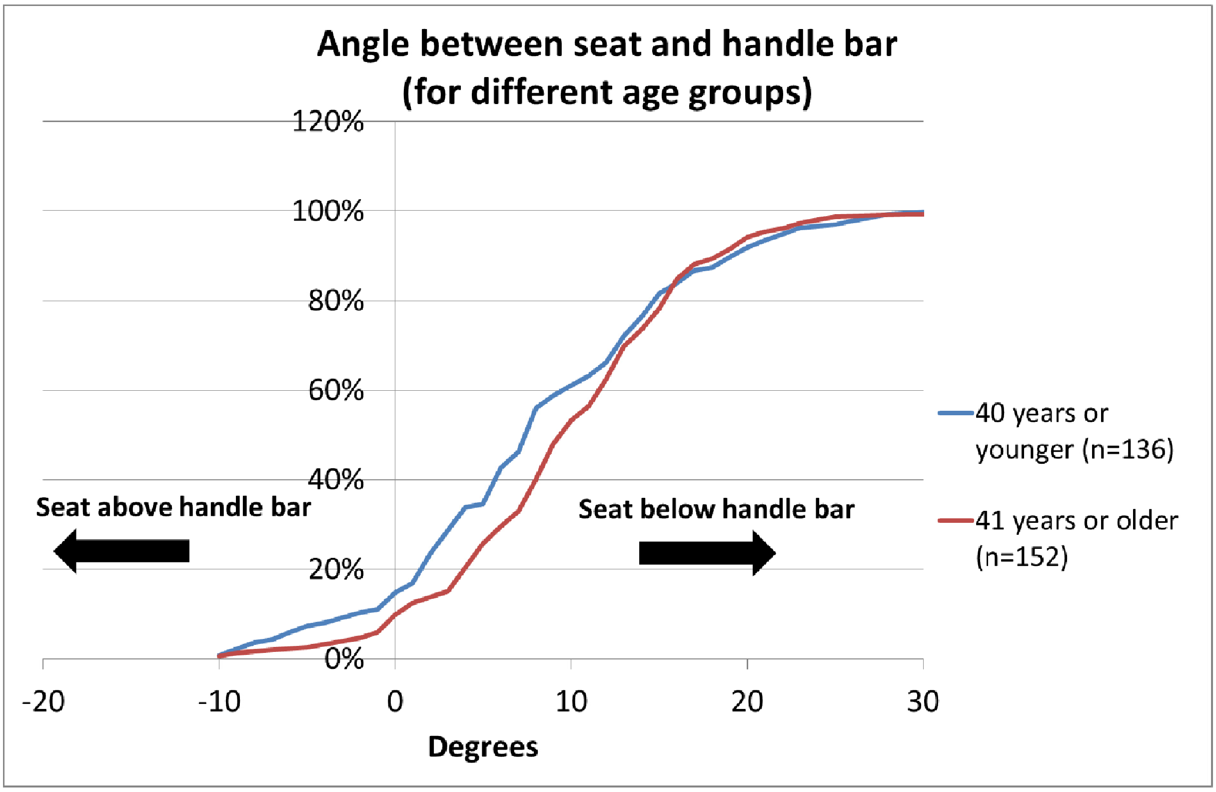


Figure 11: Angle between handle bar and seat (cumulative frequency), comparing younger riders with older riders.

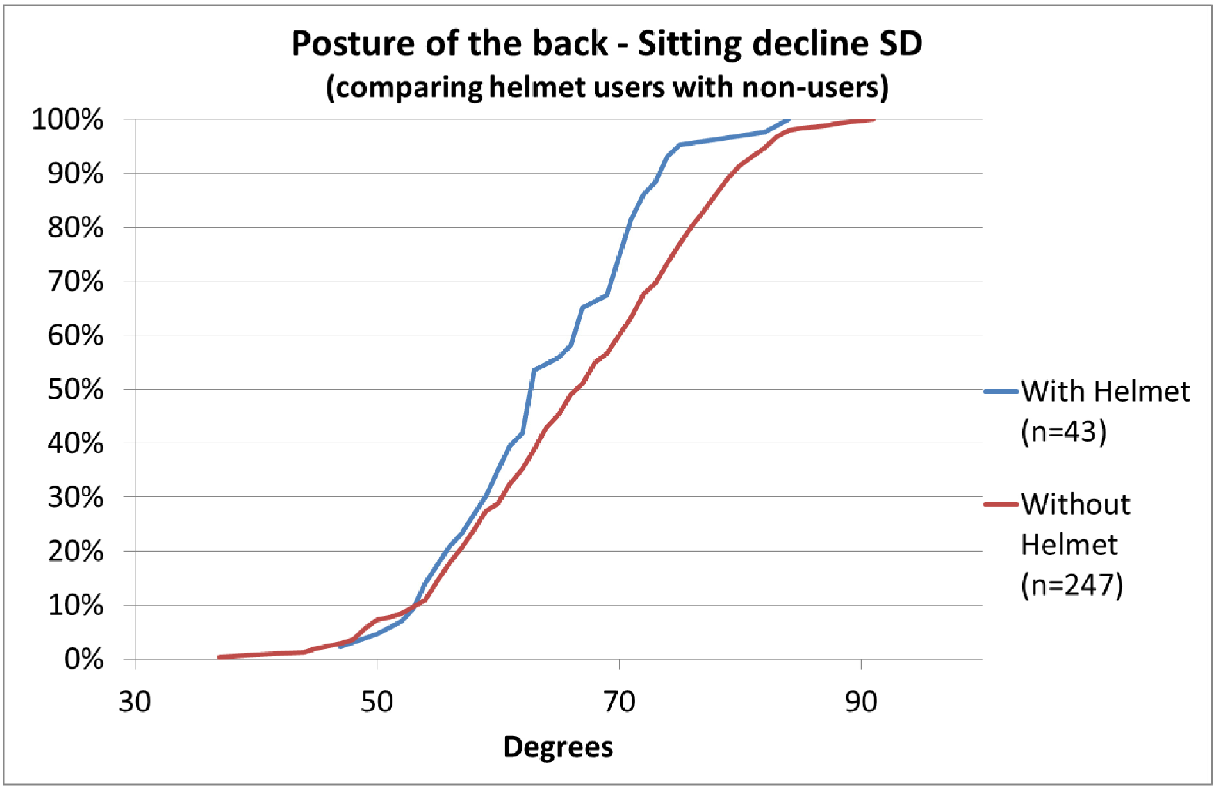


Figure 12: Posture of the back, comparing riders with and without a helmet

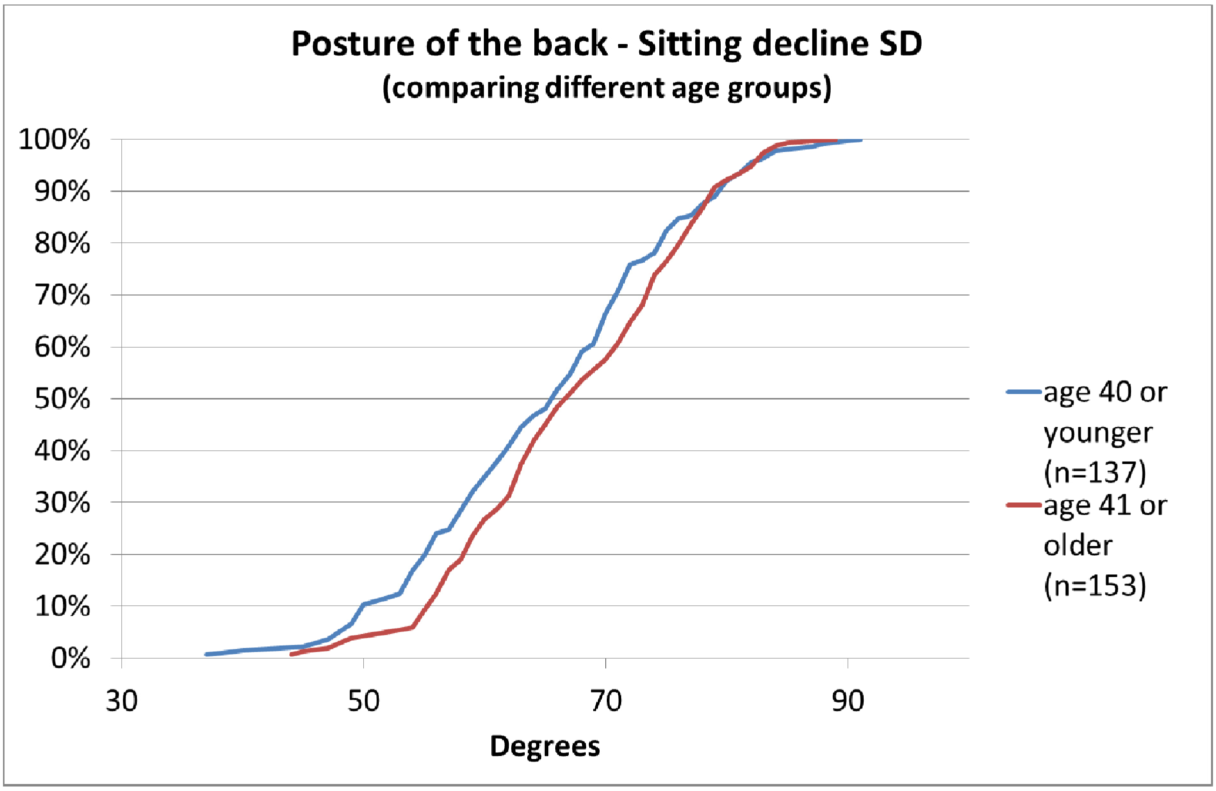


Figure 13: Posture of the back, comparing younger riders with older riders

The vertical vision limit VL due to the helmet was established by constructing a line form the eye to the front rim of the helmet (usually the sun shade) at the moment when the picture was taken. It is presumed that the influences from the momentary head movements are compensated by the high number of evaluated photos. The cumulative frequency of this angle for riders with a helmet of different age groups is displayed in Figure 14. Interestingly younger riders (40 years or younger) have found to have a higher vision angle upwards than older riders: While half of the younger riders have a vision limit upwards of just under 40 degrees, half of the older riders are just over 25 degrees and thus are at the limit of the upwards field of vision for cyclists with bicycle helmets when looking straight forward, as described in EN 1078 [2].

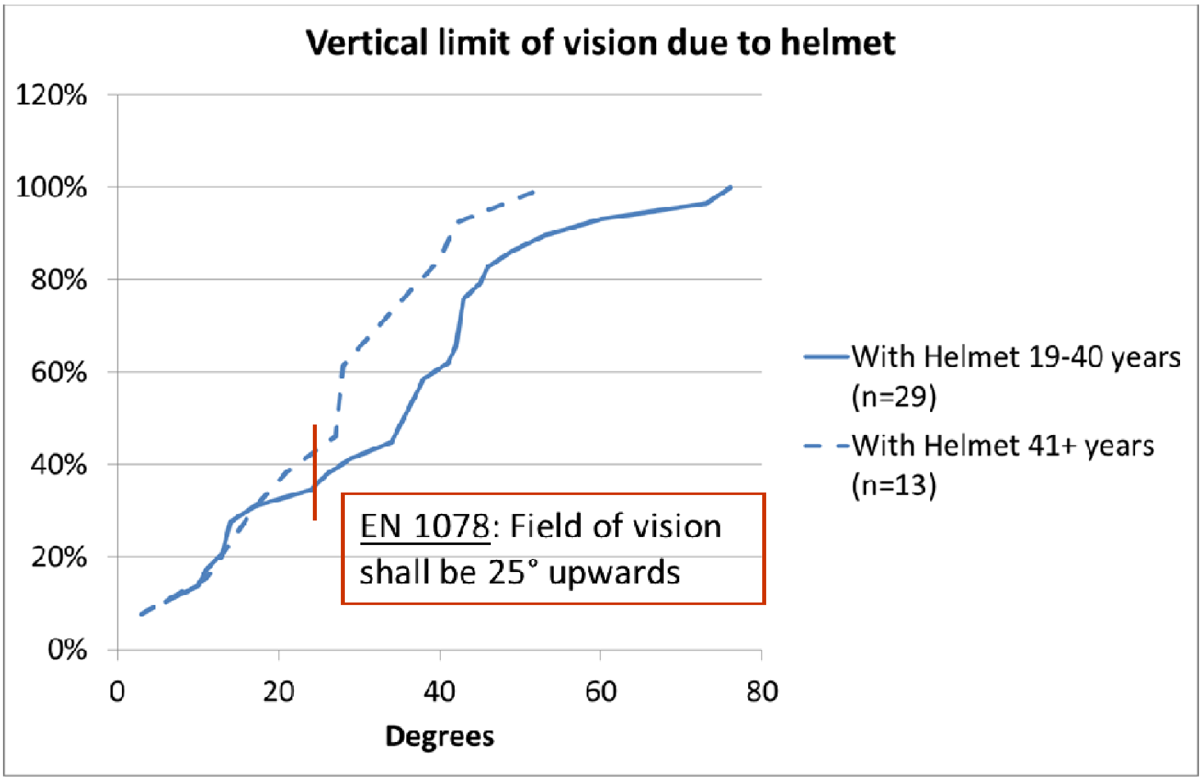


Figure 14: Vertical limit of vision due to helmet.

To investigate if the difference of the vertical limit of vision is related to the head posture (do older riders possibly lower their head more than younger riders?) the cumulative frequency of the inclination of the line between the ear and the eye are displayed in Figure 15. There seems to be no influence of the age on the head posture: for both age groups about 20% of the riders had an inclination of the ear-eye-line of 0 degrees or less (thus were looking more downwards) while nearly about 20% of the riders had an inclination of the ear-eye-line of 15 degrees or more (were looking more upwards). So if the younger riders have a higher vision angle upwards than the older riders and at the same time the head posture (looking upwards or downwards) is approximately the same for both age groups it can be assumed that older riders wear their helmets more turned forward into the face.

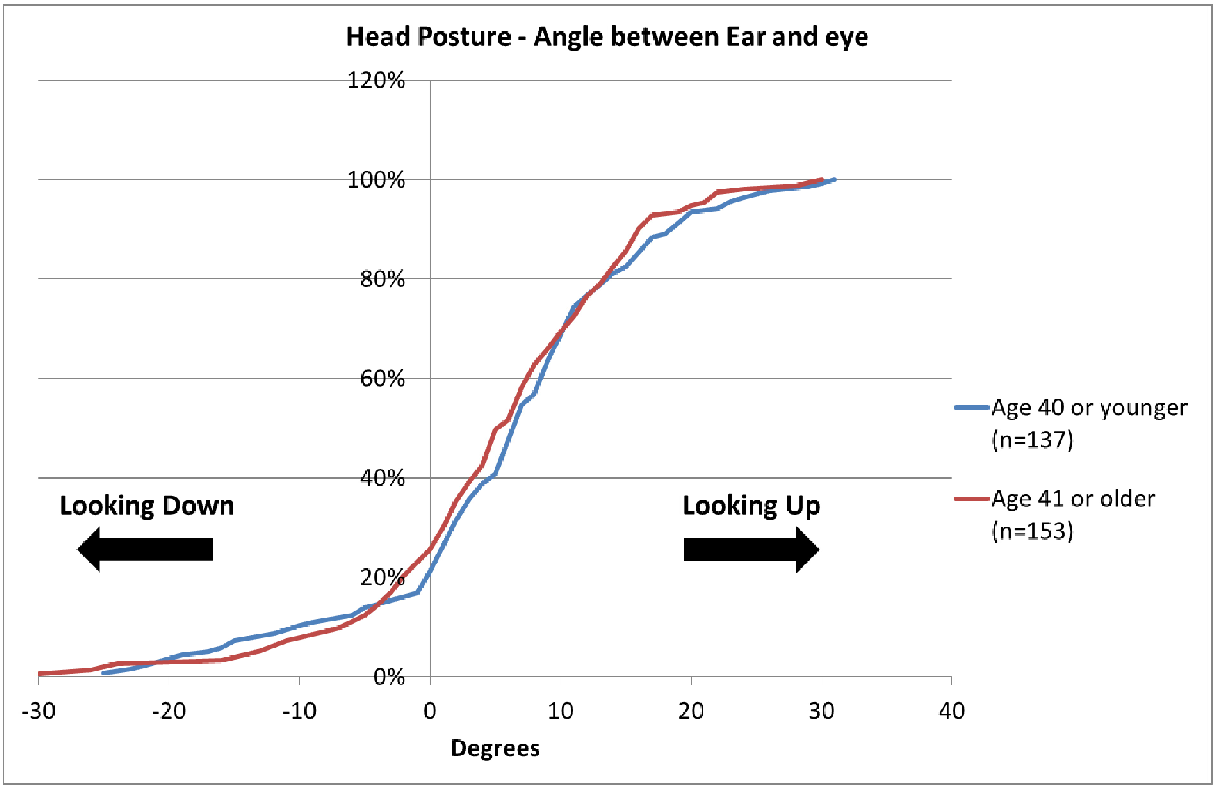


Figure 15: Head posture of riders with a helmet for different age groups.

Conclusion

The interim analysis of the two field studies (Questionnaire on helmet usage and riding posture from photos of cyclists) which were conducted by the Hannover Medical School (MHH) in the scope of COST Action TU 1101 already displayed some significant results even though only one partner and only a subsample of the target case number was available at the time of this study.

The 227 answered questionnaires which were available for the analysis are not representative for the cycling situation in the region of Hanover because the interviewed riders could not be randomly picked at random places during random times. However the study revealed that the helmet wearing rates seem to depend on the type of bicycle used. As such riders of racing bikes seem to use helmets more often than riders of other types of bicycles. It will be interesting to see if this relatively high wearing rate will be visible after the full scale study in other participating countries as well.

In general bicycle riders with or without a helmet thought that riding a bicycle is more dangerous than driving a car or walking. The reason for not wearing a helmet was mostly just carelessness or the need to carry around a helmet at the destination, while the most common reason for wearing a helmet was the feeling of safety with a helmet. So the riders are aware of the risk of riding a bicycle and believe that the helmet does have a potential for protection but carelessness and a missing solution where to leave the helmet at the destination often leads to not wearing a helmet.

Furthermore the questionnaire revealed that the helmet usage rarely leads to hearing problems of problems concerning the vision such as a narrowed field of vision. However some riders complained about unpleasant symptoms after using the helmet such as headaches. The fact that using the helmet makes you sweat more was also stated often as an unpleasant symptom.

Asked about previous bicycle accidents, those riders that had been in an accident before reported that it had mostly been a single vehicle accident where they fell off the bicycle for different reasons. Collisions with other traffic participants or with objects were rarely reported. Here the main impact zones of the helmet were stated to be the sides of the helmet and the front. Hence according to this analysis the main function of protection of the helmet should be to protect against injuries at the side of the head or at the face when hitting the ground.

For the second field study the methodology of taking pictures from bicycle riders to evaluate the seating posture has proven to be a viable technique to identify general angles describing the seating positions, even though it is not possible to identify the exact angles in every case. Together with the estimation of the age group to which the rider belongs it was possible to analyse the seating position depending on the helmet usage and the different age groups.

The incline of the line between the handle bar and the seat describes if and how much the handle bar is above the seat. Here older riders in general seem to have adjusted the handle bar higher above the seat than younger riders while at the same time there seems to be a slight bias towards higher handle bars in the group of riders not wearing a helmet – which correlates with the fact that there was a higher share of younger riders in the group of riders wearing a helmet. The posture of the upper body (sitting decline) was more upright for riders older than 40 years than for younger riders, which is certainly influenced by the higher handle bars in this group. At the same time the posture of the upper body also seems to be slightly more upright for riders nor wearing a helmet (which have a greater share of older riders). The vertical vision limit due to the helmet is determined by the front rim of the helmet (mostly the sun shade). Typical values here range from just above 0° (horizontal line from the eye to the sun shade) to 75° upwards, in which elderly riders tend to have a slightly enhanced limit upwards meaning lower vision angle. However at the same time the analysis of the head posture revealed that there is no significant difference of the posture of the head (looking upwards or downwards) between the two age groups. Hence the enhanced vertical vision limit of older riders could be explained by those riders wearing the helmet more downwards towards the face.

In general the analyses of both field studies are producing interesting results. The case numbers at the point of this interim report are still quite small, especially taking into account that only one country of the participating countries was analyzed. The full scale study will have higher case numbers with which it will be possible to verify the results found in this analysis and which will allow identifying possible differences among different countries when it comes to habits of wearing cycle helmets or influences of the helmet on the seating posture.

Literature

[1] Internetpage http://www.bicycle-helmets.eu

[2] European Standard EN 1078

Identification of new loadcases from the accident research

V S Gogate

Astt G M (Crash Safety Group), Tata Technologies Ltd Pune, India, (Permanently deputed to Tata Motors Ltd.)

Abstract

India is one of the leading countries reporting highest road accidents & related injuries. TMARG (Tata Motors Accident Research Group) has been recording crashes in association with M/s. Lokamanya Medical Foundation since 2011 with M/s, Amandeep Hospitals since Aug 2013.

This study has highlighted some accident types not discussed extensively in literature. Trucks to Truck impacts – Cabin interaction with overhanging loadbody structures and Offset underside impacts for passenger vehicles are seen in significant numbers. The paper discusses these in more detail including severity.

Keywords

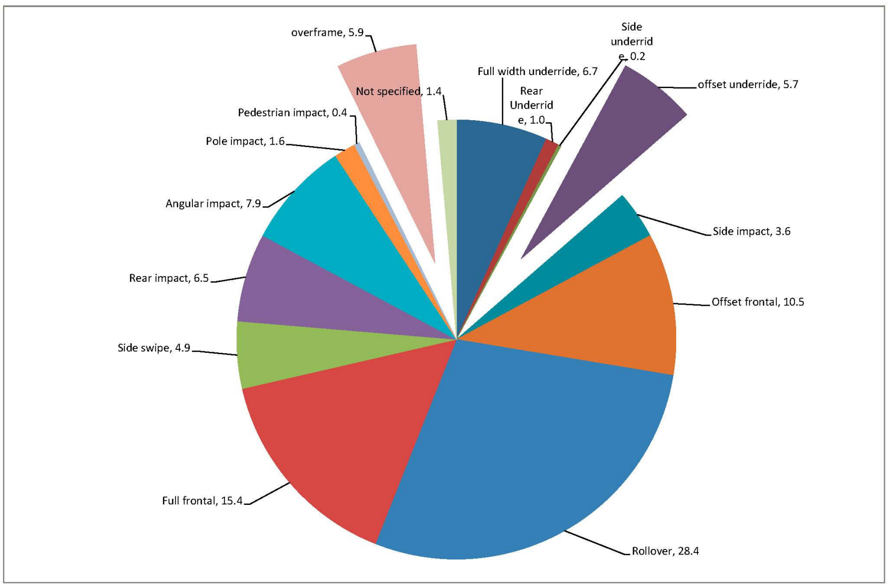
- TMARG = Tata Motors Accident Research Group
- Underride
- Overframe
- RUPD = Rear Underrun Protection Devices
- HGV = heavy goods vehicle

INTRODUCTION

Tata Motors Accident Research Group (TMARG) is recording the accident data on Mumbai Pune expressway (MPE) since 2010 in assoiciation with M/s. Lokmanya Medical Foundation, Nigdi. In Aug 2013, TMARG expanded the accident data collection domain to Amritsar Ferozpur road (AFZ) in North India in association with M/s. Amandeep Hospitals, Amritsar.

Mumbai Pune expressway is a multilane highway with traffic divided by median lane and without any crossings. It is a toll road & its

Accidents recorded by TMARG during 2010-2013



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length is 94 km. Amritsar Ferozpur road is a 2 lane undivided road with crossings (a typical of rural road) & is 120km long.
This study has identified 13 different loadcases. (Refer fig …). It contained conventional (i.e. offset frontal impacts, rollovers, full frontal imapcts) as well as non conventional type of accidents. Overframe Impacts for goods carrier vehicles & Offset Underride impacts for cars were seen to be unconventional loadcases. As crash safety engineer it was important to analyse the filed data, transform it as engineering challenge & work out appropriate interventions to reduce its impact on society. This was considered to be an important contribution to the UN initiative of "Global Decade of Actions".
This paper describes the analysis of these new loadscases on road accidents and discussion about possible interventions.

There are similarities in both these types as follows –

- the long members of the bullet vehicle does not participate in the energy absorption. The overfame impact is like underride collisions of passenger cars. The passenger compartment of bullet vehicle is loaded by loadbody of target vehicle reducing the survival space critically,
- in both types, the target vehicle is a heavy goods vehicle (HGV),
- in both types the necessary intervention is required for good carrier only,

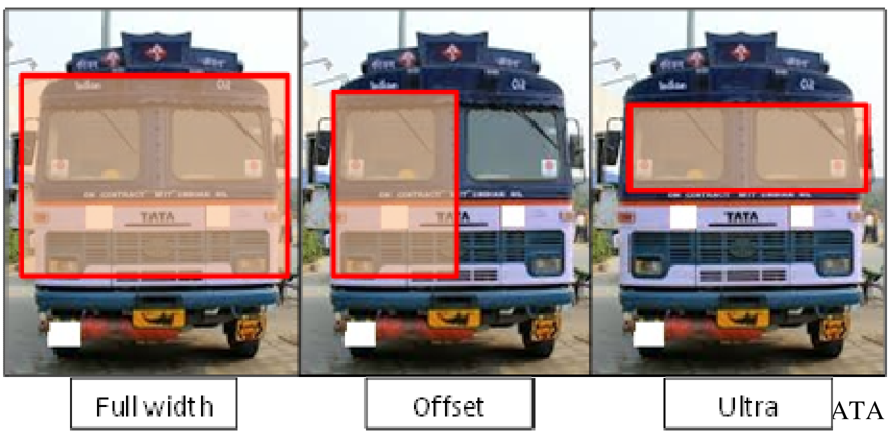
OVERFRAME IMPACTS

As seen in the fig.. This is a very grievous type accidents for HGV when one HGV impacts another HGV. In these accidents the chassis frame of the HGV does not participate in the energy absorption and the impact energy is dissipated in deformation of the passenger cabin of the bullet HGV.

This type of accident is similar to the underride crashes of cars. However there is no "underriding" of any bodyshell because of which it can not be classified as "underride". Therefore TMARG had termed it as "Overframe" accident.

The accident statistics have shown total 3 sub types of the accident scenario as follows :

- full width overframe impacts,
- offset overframe impacts – this has more reduction in survival space and cab mount failures are quite frequent. This is a scene of failed attempt to avoid accident.
- ultra overframe impact – in this the impact is oriented above the beltline. This sub type forms a minority of the accidents,



167C

Full width

483G

Offset

123C

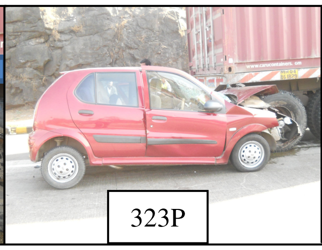
Ultra

The statistics of this accident type is –

- 5.9% were "overframe" type of accidents. Out of which 41% were of full width type & offset type each. The Ultra overframe type were 19%,
- 24% of the overframe accidents were fatal (of that 22% were full width overframe, 44% were ultra overframe & 66% were offset overframe).

OFFSET UNDERRIDE CRASH TESTS

This loadcase was created out of the total underride crash tests because of its severity & challenges involved in the interventions. When a small vehicle impacts a heavy vehicle wherein part width of smaller vehicle & of heavy vehicle is involved in the energy absorptions.



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The statistics of this type of accidents is as follows :

- 11.5% accidents were reported to be of underride. Half of these accidents had the heavy vehicle fitted with rear underrun protection devices (RUPD),
- 5.2% of them were of full width underride & 6.3% were of offset underride collisions.
- 14.6% underride accidents were fatal with 3:4 distribution between offset underride & full with underride.
- 17.6% persons were fatally injured in underride accidents. 7.4% fatalities were in full width underride & 10.2% fatalities were in offset underride type accidents,

Discussions

Both these crash cases were studied and following are details of the analysis -

Overframe impacts -

The loadcase is similar to ECE R29 pendulum impact test however it is more severe for the following reasons –

- The impact energies are quite high,
- Widthwise or heightwise offsets results into load concentration leading to severe deformation of the passenger cabins and reduction in survival space,

Some of the key observations on this type of accidents are –

- Provision of RUPD (on bullet vehicle) and FUPD (on target vehicle) does not prevent these accidents. A probable reason could be the difference in level of UPD interaction and centre of gravity (COG) of the vehicle. In fact the inertia forces & the UPD reaction would produce a couple that will promote the interaction of the passenger cabin as shown.

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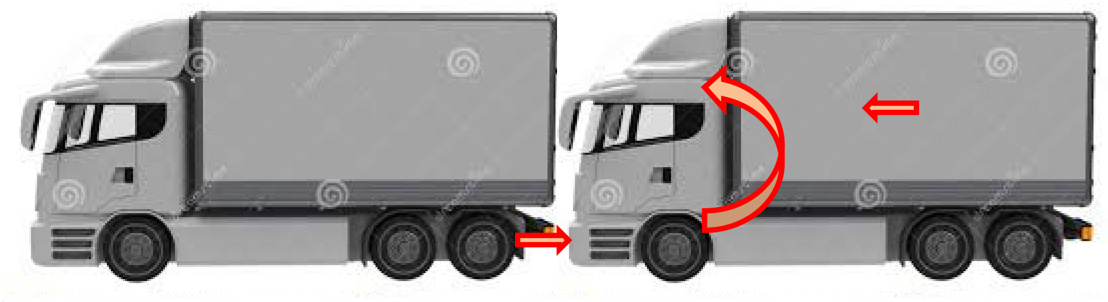

- Breakage of cab mounts :
    - The front cab mounts are under higher stresses & in many cases they were found broken. However breaking of cab mounts found to be desirable as it retains the survival space (provided there is adequate space for movement of the cab).
    - In case of offset type of overframe impacts, the cab is under rotational moments which also lead to breakage of cab mounts.
    - Subsequent to the front cab mount failure, the cab tilts about the rear mounts. Such tilting helps to reduce the cab deformations & thus improves survival space.
    - When can tilts, there is a dissociation of steering linkage (either due to breakage or due to disconnect the spline joint) which is also desirable as it prevents the steering wheel intrusion.
- When the cab deforms, the A pillars are under higher stresses & in some extreme cases they have lost their integrity with the roof structure.

In a possible solution, there is a need to provide protective structure at the level of COG of bullet vehicle which would engage with impacting structure & prevent an undesirable cabin loads. However it appears to be unpractical. Therefore a more emphasis to "accident avoidance" seems to be the best possible intervention

Offset underride impacts -

The data show that the RUPDs are effective in mitigating the full width underride collisions, however they are not effective in offset underride crash tests. The following accidents show that the overhanging portion of the RUPD bends under impact & does not avoid

underride. The severity is more with vehicles with shorter bonnets/flat front/forward control vehicles.

The same situation was reproduced in CAE environment & the behavior was confirmed :

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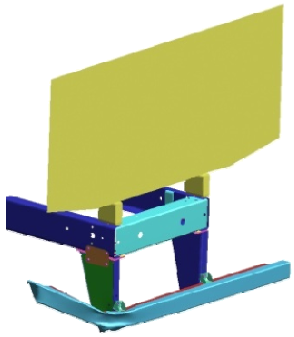
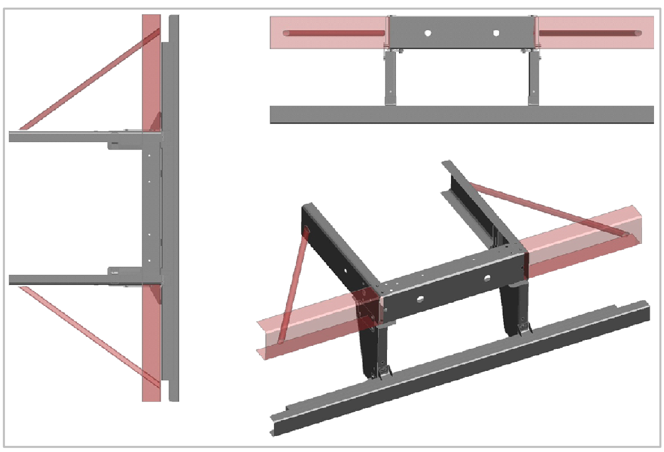


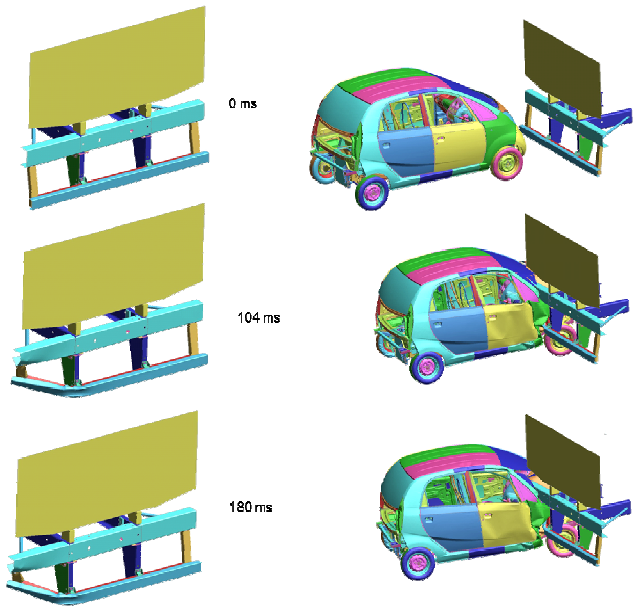
the generalized sequence of this type of accident is as follows :

- The smaller vehicle structure hits the end of the RUPD ,
- Bends it & continues to move ahead,
- The loadbody installed on HGV interacts with either of the A pillar and/or the windshield of the small vehicle. At times the loadbody interacts with the roof structure as well. This is particularly observed when the ground clearance of the bottom end of the chassis frame is ≥1000mm.
- The smaller vehicle comes to halt when its structure (A pillar, roof etc.) are adequately deformed & the kinetic energy is completely absorbed.

Increasing strength of the RUPD is quite challenging & adds up excessive material since supporting the unsupported end is a challenge and there is no vehicle structure available which would provide the additional strength.

An alternate solution was worked out by extending the end cross member of the cassis frame of a goods carrier as shown[1]. It "wedges" the sloping bonnet & stop the smaller vehicle from underrunning. The following sketches explain the same.





[1] This concept has been applied for patent vide Indian Patent Application 610/Mum/2014.

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CONCLUSIONS

- Accident research provides inputs which are beyond any conventional safety strategies.
- Overframe impacts for good carrier & offset underride impacts for passenger cars are important loadcases on Indian roads that require attention for improving the road traffic injuries (RTI),

ACKNOWLEDGEMENT

The author appreciates the efforts put in by members EMS teams from M/s. Lokmanya Medical Foundation & M/s. Amandeep Hospitals for recording of the accidents on road round the clock. He would also like to appreciate the efforts put in by Mr. V A Pachore, Mr. A A Thorat & Mr. G N Gawhale for conducting the CAE analysis of the new loadcases and reproducing the field performance of the accident vehicles. Without these efforts, it would not have been possible to institutionalize these loadcases. The author is thankful to the management of Tata Motors Limited for providing opportunities & support for the research activities.

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Evaluating human-machine-interfaces for making binary choices: why measuring uncertainty is important and how to do it

A. Baier and A.C. Zimmer

Engineering Psychology Unit, University of Regensburg, Germany

Abstract - Many safety-relevant tasks in control or diagnostics require binary choices such as 'conflict vs. separation' in air-traffic control, 'normal vs. pathological' when interpreting x-ray pictures, or 'permitted vs. forbidden' when inspecting airport security scans. Deciders often are uncertain, but nevertheless required to decide between two alternatives, that is, they have not only to decide upon an action, but also about the admissible level of uncertainty. If the accepted level of judgment certainty is not taken into account, the sequence of decisions does not capture the full picture of the underlying decision process. Differences in judgment certainty are relevant, because they reflect not only the adequacy of the human-machine-interface that is evaluated, but also the differences in expertise of the decider and the requirements of the actual situation or task. Therefore, capturing both judgment certainty and discrimination performance is essential. A comparison of different human-machine-interfaces (for air traffic control) is used to illustrate a methodological approach, which allows for integrated analyses of decision processes based on receiver-operator-characteristics and practical guidelines for the evaluation of human-machine-interfaces for safety-relevant operation procedures are provided.

INTRODUCTION AND THEORY

Many tasks in control or diagnostics require the deciders to make binary choices such as 'conflict vs. separation' in air traffic control, 'normal vs. pathological' when interpreting x-ray pictures, or 'permitted vs. forbidden' when inspecting airport security scans. Although deciders often are uncertain, a choice between the two alternatives that formally can be defined as 'positive' and 'negative' nevertheless is required, therefore causing a dilemma: For achieving a high performance in discriminating between positive and negative cases, the decider has to maximize the fraction of true positives (hit rate) out of the total actual positives, and minimize the fraction of false positives (false alarm rate) out of the total actual negatives at the same time. Unfortunately, in all cases in which the decider is not absolutely certain about the correctness of his decision, raising the true positive rate requires to classify more and more cases as positive even though uncertain if they are indeed positives. Hence, increasing the true positive rate is inevitably accompanied by an increased likelihood for a false alarm and vice versa. The decider has to choose between striving for the maximization of the former and therefore tolerating more false alarms, and striving for minimization the latter and therefore diminishing the number of true positives, or aiming to reach a balance between the resulting true positive and false alarm rate. The discrimination performance, however, stays unaffected from this choice, which shall be illustrated with the following example. If the decider is absolutely uncertain but wants to ensure that no positive case is missed, he classifies all cases as positives. Consequently, all negatives will be also classified as positives, resulting in a discrimination performance at chance level. The same performance results when, for instance, both half of the positives as well as half of the negatives are classified correctly. Though the discrimination performance in both examples is the same, the underlying decision process is a different one, because in the latter the decider accepts a higher degree of uncertainty. The result of the choice about how much uncertainty should be accepted is termed 'criterion' and categorized into 'liberal', 'conservative' and 'neutral' response behaviour. The liberal criterion reflects the tendency to classify uncertain cases preferably as positives rather than negatives [1].

WHY MEASURING UNCERTAINTY IS IMPORTANT

For the evaluation of human-machine-interfaces used to make binary choices, analyzing both the performance and the judgment certainty is of mayor importance, because the outcome of the decision-process in terms of true positive and false positive rates is not only a result of how well the human-machine-interface supports the decider in discriminating between positive and negative cases, but also is a result of the level of uncertainty the decider is willing or allowed to accept. There are several important factors in the context of evaluating human-machine-interfaces that, besides the design characteristics of the human-machine-interface, impact on the decision of the decider: His expertise with the interface (i) and the task (ii), as well as the characteristics of the task (iii) and the situation (iv). Interactions between these factors can additionally impede the interpretation of the results. The following examples shall point out how they can lead to counterintuitive effects.

i) While a decider is able to discriminate between the majority of the positive and negative cases presented with the interface he or she is highly used to, a novel interface might cause a higher degree of uncertainty, encouraging him or her to apply a more liberal response criterion. Therefore, both a higher true positive and false positive rate result with the novel interface. The discrimination performance with the novel interfaces, however, could well be equal, better, or worse as with the traditional interface.

ii) The same is true when the decider possesses profound expertise with the tasks. He or she might be equally certain about the presented cases, but achieve an equal, better, or worse discrimination with the novel interface.

iii) Another possibility is, that certain tasks such as vertical distance judgments cause a higher uncertainty when, for instance, presented with a 2D compared to a 3D visualization, whereas for horizontal distance judgments the contrary might be true. Such an interaction between human-machine-interface and task-characteristics might conceal existing differences, by resulting in both an overall comparable discrimination performance and judgment certainty, though clear advantages exist for each kind of visualization dependent on the task to be achieved.

iv) In general, the risks and incentives certain situations comprehend play an important role when deciding how much uncertainty is acceptable. While an air traffic controller often has only one opportunity to decide, and a wrong decision is likely to cause fatal consequences, he or she will apply a liberal response criterion. Medical doctors or airport security officers, in contrast, might show a stronger trend towards conservative response behaviour because they face different demands. If uncertain, they might decide to conduct another test in order to re-evaluate the diagnosis before informing a patient about a radical result or allowing a passenger to enter an airplane.

These examples highlight that an objective evaluation requires separating discrimination performance from response behaviour to enable a correct interpretation of the results.

METHODS FOR EVALUATING PERFORMANCE AND UNCERTAINTY

Selecting test cases and rating procedures

As a basis for the measurement, a representative set of cases that includes as many typical task characteristics as possible has to be presented, and is so much the better the more cases are used [1]. To facilitate the interpretation of the results, it is helpful to present the decider with an equal number of positive and negative cases in a randomized order. Right after the presentation of each case, the decider is asked to classify it as positive or. To do so, a rating scale with an at least ordinal scale of measurement should be used. We recommend using a six-point-rating scale that allows for capturing an interval level of measurement, a so-called Likert-scale. The even number of response options forces the decider to indicate a tendency towards one of the two endpoints. The interval scale allows conducting a broad variety of statistical calculations on the resulting data. More than six options tend to overload the decider, whereas less might limit the decider in expressing the perceived level of certainty and the comprehensiveness of the resulting information.

Calculating hit and false alarm rates and visualizing performance: The ROC curve

After the rating procedures have been completed, first both hit and false alarm rates for each response option and human-machine-interface that shall be evaluated are calculated. Afterwards, and beginning with the resulting hit and false alarm values for the option ‘certainly positive’, the hit and false alarm rates of the next response option ‘probably positive’ and so forth are added, producing pairs of hit and false alarm values that increase with adding each option until a value of 100% results. Based on this, a so-called receiver operating characteristic (ROC) curve can be created to demonstrate the performance resulting with each human-machine-interface. To do so, the values are plotted into a coordinate system in which the ordinate represents the hit rate and the abscissa the false alarm rate, and connecting the data points including the zero scale marks.

Isolating performance from uncertainty: The area under the ROC curve

The area under the ROC curve (AUC) indicates the likelihood with which the decider detects a true positive case correctly as such when presenting a randomly chosen case out of all cases on which the ROC curve is based. The AUC value can vary between the two values 0 and 1 of which the latter indicates a perfect discrimination performance. A result of 0.5 signifies a performance at chance level. The AUC value therefore serves as a measure for expressing the discrimination performance independently from the underlying judgment certainty, since it solely depends on the size of the area under the curve and not on its shape. That is, the criterion can vary on the graph, therewith representing different response criteria that could be applied when uncertain about if the displayed case is positive or negative. The discrimination performance, however, stays the same no matter which response criterion the decider applies for each response option [1]. This facilitates an objective comparison of different human-machine-interfaces superior to comparing hit or false alarm values directly because the latter depends on the response criteria the deciders apply.

Comparing performance while controlling judgment certainty: The zROC graph

By transferring the hit and false alarm values into standardized z-values, connecting them with a straight line by calculating a linear equation, and plotting them into a coordination system with equally standardized axis, for any desired hit rate the resulting false alarm rate can be predicted and vice versa. These so called zROC graphs facilitate the evaluation of different human-machine-interfaces in a way that goes beyond comparing the discrimination performance on the basis of the AUC values. The evaluator now can choose from any criterion a decider might want to apply in order to deal with uncertainty, and compare the resulting performance between the different human-machine-interfaces. The fact that the deciders may have applied different criteria with each interface is irrelevant. Please note that determining zROC graphs is so much the better, the more response options have been given. A binary response option, however, does not allow the calculation of a zROC graph, because it only allows calculating one point of the graph and the required information for determining the slope of the zROC graph is missing unless, for instance, assumptions can be derived from similar experiments.

HOW TO GATHER, ANALYZE AND INTERPRETE YOUR DATA

Comparing expert performance with a traditional and a novel interface: An example from air traffic control

To illustrate how the results from comparing different human-machine-interfaces for making binary choices can be analysed and interpreted with the above described methodology, we use a data set from a recent study in which we compared different visualizations for air traffic controller workstations [2]. Amongst others, we used a representative set of 32 safety critical air traffic scenarios that were presented to 12 air traffic controllers whose task it was to classify each scenario as conflict (positive) or separation (negative) using a 2D visualization similar to the one used today at air traffic controller workstations as well as a stereoscopic 3D visualization. Each scenario started 45 seconds before the respective aircraft actually collided or reached the closest point of approximation in case they missed each other, and was shown for exactly 10 seconds before it was blinded out. After each scenario, an entry mask with a six-point-rating scale and the response options ‘certainly positive’, ‘probably positive’, ‘maybe positive’, ‘maybe negative’, ‘probably negative’, and ‘certainly negative’ was presented. This allowed the air traffic controllers to express their certainty about the outcome of each scenario. Table 1 shows the percentages of true positive and true negative scenarios that were classified with each response option and visualization.

Table 1. Percentage of positive and negative cases classified with each response option.

	Scenario type	certainly yes	probably yes	maybe yes	maybe no	probably no	certainly no
2D	Positive	25,1	39,9	7,4	6,9	11,3	9,4
	Negative	2,8	9,7	4,5	5,2	24,4	53,4
3D	Positive	22,0	37,0	9,5	8,0	19,5	4,0
	Negative	5,6	10,0	4,5	7,3	20,6	52,0

The percentages of true positive and true negative scenarios provide the basis for calculating the hit and false alarm pairs used for creating the ROC curves. Table 2 shows the results of cumulating the percentages beginning with the response option ‘certainly yes’ that are added to the values of the other response options beginning with ‘probably yes’ and so forth.

Table 2. Cumulated hit and false alarm rates over the response options beginning with ‘certainly yes’.

	Scenario type	certainly yes	probably yes	maybe yes	maybe no	probably no	certainly no
2D	Hit rate	25,1	65,0	72,4	79,3	90,6	100
	False alarm rate	2,8	12,5	17,0	22,2	46,6	100
3D	Hit rate	22,0	59,0	68,5	76,5	96,0	100
	False alarm rate	5,6	15,6	20,1	27,4	48,0	100

For illustrating the performances, the cumulated hit and false alarm rates for both the 2D and the 3D visualization are plotted into a coordinate system with the ordinate showing the hit rate and the abscissa the false alarm rate. Connecting all points including the zero scale marks result in the ROC curves shown in Figure 1a. For transforming the ROC curves into zROC graphs, first the hit and false alarm rates of Table 2 are transformed into standardized z-values by dividing them by 100 and consulting the respective z-values. Table 3 shows the results of this transformation. Please note that for the response option, for which the cumulated hit and false alarm rates amount to 100% per cent, no z-values can be reported, because z-values of the standard normal distributions range from $-\infty$ to $+\infty$.

Table 3. z-values of the cumulated hit and false alarm rates from Table 2.

	Scenario type	certainly yes	probably yes	maybe yes	maybe no	probably no	certainly no
2D	Hit rate	-0,67	0,39	0,59	0,82	1,32	---
	False alarm rate	-1,91	-1,15	-0,95	-0,77	-0,09	---
3D	Hit rate	-0,77	0,23	0,48	0,72	1,75	---
	False alarm rate	-1,59	-1,01	-0,84	-0,60	-0,05	---

For these values linear regressions are calculated. In the case of the 2D visualization, a slope of 1.1 and an intercept with the axis of ordinates of 1.56 within the z-score-based coordinate results. For the 3D visualization these values amount to 1.61 and 1.8 respectively. Both the calculation of the z-values as well as of the linear equations can be completed using commercial spreadsheet programs. Afterwards, the standard normal values of the hit and false alarm rates as well as the results of the linear equations are plotted into a coordinate system similar to the one used for displaying the ROC curves but with z-standardized axis. The zROC graphs are shown in Figure 1b, using a z-value-range from -2.5 (1%) to 2.5 (99%).

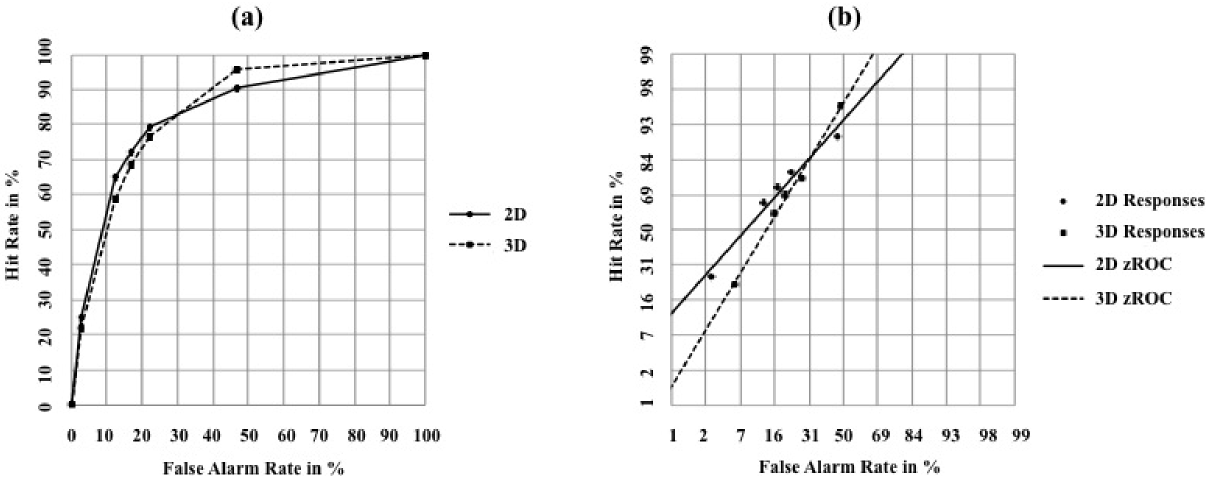

Figure 1. ROC curves (a) and zROC graphs (b) based on the hit and false alarm rates of the air traffic controllers with the 2D and the 3D visualization.

Which human-machine-interface leads to the best overall discrimination performance?

In order to evaluate the resulting discrimination performance with 2D and 3D, the areas under the both ROC curves shown in Figure 1a are compared. For the calculation of the AUC values, we refer to Green & Swets [1], because manually determining them is somewhat complex, and the description of the mathematical foundations required doing so would go beyond the scope of this article. We rather recommend using one of the various commercial statistics programs that offer the possibility to calculate AUC values, e.g. SPSS. Our results indicate that the use of the 2D visualization results in AUC value of 0.834 while the 3D visualizations leads to a result of 0.815. Hence, the likelihood for correctly classifying a randomly chosen case out of the 32 scenarios as conflict or separation is 83.4% when presented with 2D, and 81.5% in case 3D is used. Because the AUC values only refer to the size of the area under the ROC curves and neglect their shapes, this advantage of 2D over 3D is independent from the underlying judgment certainty, and reflects the average performance that is to be expected, no matter which criterion the air traffic controller decides to apply. This constitutes a major advantage over other methods for comparing the performance between human-machine-interfaces used for making binary choices, because the factors that impact on the deciders' judgment certainty and his or her decision about which criterion to apply in order to deal with uncertainties can be disregarded.

How does the response behaviour impact on performance?

In some cases the response criterion cannot be disregarded, but rather is of major importance. In air traffic control, for instance, the response behaviour is central, because safety is to be prioritized higher than efficiency, and the consequences of overlooking a conflict are worse than causing a false alarm. In this case, performance shall be measured by the amount of false alarms that result when the decider tends to favour the classification of uncertain cases as positives rather than negatives. Hence, the criterion by which the performance of the decider with different interfaces is compared matters. Transforming the ROC curves into zROCs allows the evaluator to choose the criterion by which the human-machine-interfaces shall be compared. In our example, either hit rates reported in studies from other researchers or the hit rates that resulted with the visualizations we evaluated constitute suitable reference values. The former allows for an invaluable comparison with other systems, while the latter offers a comparison between the traditional 2D top-view visualization currently used at air traffic controller workstations and the novel 3D visualization. Using the linear equation that describes the performance of the air traffic controllers with the 2D visualization, a false alarm rate of 57% is predicted for a criterion that leads them to classify 96.0% of the actual conflicts as such. This predicted value now could be compared with the false alarm rate of 48.0% that resulted with the 3D visualization for the hit rate of 96.0%. The result indicates that by using the 3D visualization, a 9% lower false alarm rate can be expected compared with using the traditional 2D top-view when an equal conflict detection performance as with 3D shall be guaranteed. Please note that, because the linear equations are based on the z-transformed, values z-values have to be used for the calculations and that the result has to be converted into percentile ranks for its interpretation.

Interestingly, the result of comparing the false alarm rates between 2D and 3D shows the very revers result of the AUC comparison. While in the former comparison 3D turns out to be the advantageous visualization, the latter demonstrates 2D to be superior. The reason for this, as can be seen in Figure 1b, is the different slopes of the zROC. Therefore, the result depends on the response criterion of the decider and, in our example, the more liberal the criterion, the higher the advantages of 3D and vice versa. Hence, in other applications than air traffic control where it might be preferable to minimize the false alarm rate rather than maximizing the hit rate, e.g. because the costs of a false alarm outbalance those of missing a positive case, the application of conservative response behaviour is conveyed, and the same results would indicate 2D to be the preferred visualization. The reason for different zROC slopes lays in the variation of the deciders' responses when rating positive and negative cases. Figure 2 shows two examples of probability distributions that could result from rating scenarios on a six point Likert-scale. The graph to the right indicates the probability distribution that results from rating the positive scenarios, the left from rating the negative scenarios. In Figure 2a, an example is given in which the variation from the average value of the judgments is equal for both positive and negative cases. This leads to a unit slope of the zROC, because the growth of the probability for identifying a positive case as such when allowing more and more uncertainty (moving the criterion from the right hand side of the graph to the left hand side) increases in the same manner as the probability for a false alarm. The example depicted in Figure 2b shows two distributions with the same average values as the example in Figure 2a. Therefore, the discrimination performances of both examples are equal. In the example shown in Figure 2b, however, the standard deviation of the responses to the negative cases is larger than the deviation of the responses to the positive cases. Consequently, when applying a more conservative criterion, the probability for a false alarm initially is higher compared with the example of Figure 2a, but increases less when moving towards more liberal responses. When plotting both examples into a z-coordinate system, the example in Figure 2b therefore will result in a steeper zROC slope as the example shown in Figure 2a.

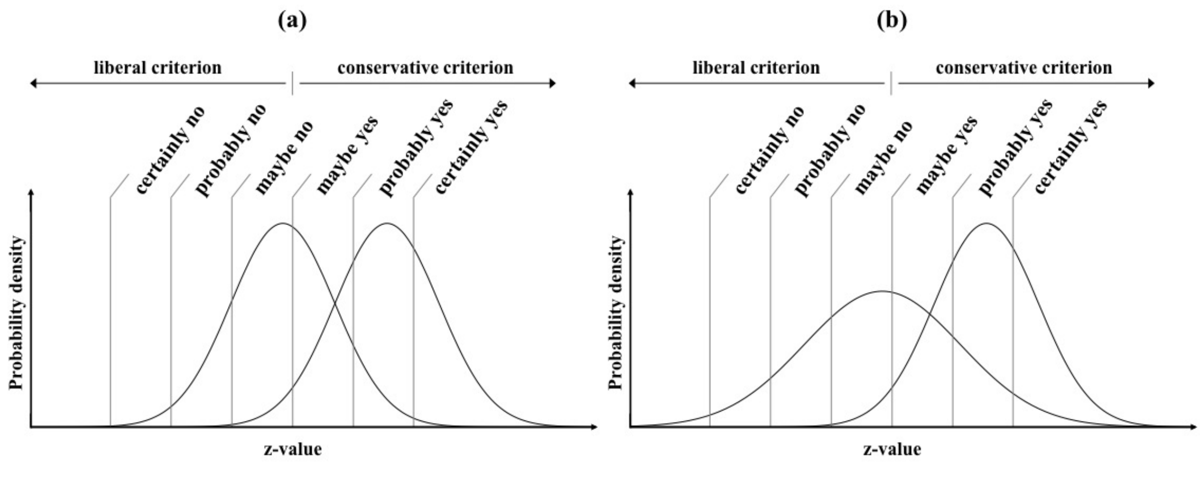

Figure 2. Exemplary distributions that result when the variances of the rating positive and negative cases are equal (a) or different (b).

In our air traffic control example, the positive and the negative scenarios were almost equal. While all factors such as horizontal and vertical aircraft speeds, directions, and approach angles were the same for both positive and negative cases, within the latter horizontal and vertical separations were created by separating their trajectories in the accordant direction. Hence, distinguishing a horizontal separation from a conflict only required the perception of the horizontal aircraft trajectories, whereas a vertical separation could be discriminated from a conflict by processing the vertical aircraft trajectories alone. Because of the characteristics of the visualizations, the air traffic controllers were more certain when judging vertical separations with 3D, but less certain when horizontal separations where displayed. That is, their expertise with 2D visualizations vanishes in case of vertical separation.

Which response behaviour offers the best trade-off between hit and false alarm rate?

For some applications it is important to know the response criterion that offers the best trade-off between hit and false alarm rate. This might be the case when the binary choice is one of many in a process, and therefore optimizing the criterion does not impede the overall efficacy as could be the case in airport security scans. The best criterion can be determined by selecting the highest value that results from calculating the Youden-index [1], which is calculated by adding the sensitivity (hit rate) to the specificity (1 - false alarm rate) and subtracting one. In our example with the air traffic controllers, the best trade-off between hit and false alarms for both visualizations results, if all cases that fall in the response options from 'certainly yes' till 'maybe no' would be treated as conflicts and all cases that are classified with 'probably no' and 'certainly no' as separations.

DISCUSSIONS AND CONCLUSIONS

A common concern about using rating scales with more than two response options is that either before or after gathering the data, the evaluator has to define a criterion to decide which cases are positive and which are negative. This is of special concern when this criterion has to be chosen arbitrarily. The above-described procedures illustrate that by reporting the sizes of the areas under the receiver operating characteristic curves, no such decision is required for evaluating the discrimination performance. Though the area under the curve can be calculated on the basis of binary responses, using an appropriate Likert-scale offers several advantages for the evaluation of human-machine-interfaces. As stated above, the area under the curve offers measure of performance that is independent from judgment certainty, and allows for an objective comparison of the discrimination performance without the results being influenced by the deciders' applying different response criteria with the human-machine interfaces as a reaction on differences regarding expertise or characteristics of the task or situation. Moreover, using a Likert-scale allows the evaluator to assess the performance for any criterion or choosing one by which the performances are compared. Also the determination of the most efficient response criterion is possible and can be used for training deciders in order to achieve the best trade-off between positive and false positive decisions. Above all, using a Likert-scale facilitates the deciders in rating the cases, because they are not forced to give a yes or no answer though they are uncertain.

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Tool box for the benefit estimation of active and passive safety systems in terms of injury severity reduction and collision avoidance

H Liers, L Hannawald*

*Verkehrsunfallforschung an der TU Dresden (VUFO) GmbH, Semperstraße 2a, 01069 Dresden

Abstract

The evaluation of the expected benefit of active safety systems or even ideas of future systems is challenging because this has to be done prospectively. Beside acceptance, the predicted real-world benefit of active safety systems is one of the most important and interesting measures. Therefore, appropriate methods should be used that meet the requirements concerning representativeness, robustness and accuracy.

The paper presents the development of a methodology for the assessment of current and future vehicle safety systems. The variety of systems requires several tools and methods and thus, a common tool box was created. This toolbox consists of different levels, regarding different aspects like data sources, scenarios, representativeness, measures like pre-crash-simulations, automated crash computation, single-case-analyses or driving simulator studies. Finally, the benefit of the system(s) is calculated, e.g. by using injury risk functions; giving the number of avoided/mitigated accidents, the reduction of injured or killed persons or the decrease of economic costs.

MOTIVATION

There is no doubt that efforts in the field of passive safety have increased the level in traffic safety. Many seriously and fatally injured persons could be saved by passive (secondary) safety measures in the last decades. The benefit of such systems can be evaluated by comparatively simple methods because they only act in accident situations. Comparing vehicles with and without system in similar accident constellations (e.g. with a retrospective analysis on the basis of real accident data) will bring reliable results for the benefit of passive safety systems.

Since the 1990s another field of vehicle safety became more and more important – the active (primary) safety. The focus in vehicle safety is continuously changing from passive to active safety. Due to the fact that active safety systems are able to avoid or mitigate accidents new methods are required for the benefit assessment because systems change the entire situation whilst passive measures “only” affect the consequences of a crash. Furthermore, the linkage of passive and active safety systems (commonly named as integrated safety) is another important fact that has to be considered.

The benefit of few active safety systems, which are already frequently available in the current fleet (e.g. ABS, ESC or brake assist), can also be estimated in a retrospective manner. However, the evaluation of the expected benefit of new/current systems or even ideas of future systems is challenging because this has to be done prospectively. Beside acceptance, the predicted real-world benefit of active safety systems is one of the most important and interesting measures. Therefore, appropriate methods are necessary which should provide reliable results.

The Traffic Accident Research Institute at the University of Technology Dresden (VUFO) has many years of experience in the benefit evaluation of safety systems. One experience says that the large variety of systems and their combinations requires a several tools and methods. The VUFO tried to integrate all of them in a common tool box. One important fact is that in future not only the real system benefit in accident situations should be evaluated but also the user acceptance should be considered. Therefore, still other methods or at least other data sources are necessary.

METHODOLOGY

At first the scope has to be described in short. It is well known that traffic safety is not only a matter of car manufacturers and their suppliers. A lot of other parties from different scientific fields are also developing and providing measures for an enhanced traffic safety, represented by the 4 E's – Engineering, Education, Enforcement and Encouragement. However, the developed toolbox is primarily focused on vehicle-related safety measures (i.e. especially passive, active and integrated safety).

In general the question about the possible benefit of a new safety system arises before or during the development process. For existing systems the same question may be asked after a certain time on the market. The biggest challenge for a standardized benefit estimation process is the large variety of existing or future systems. Another frequent problem is the availability of appropriate data and reliable assumptions about the functionality / effectiveness of safety measures. The most evaluation methods can be described by the following process scheme (Figure 1), independent if the benefit in the accident scenario or the acceptance should be evaluated:

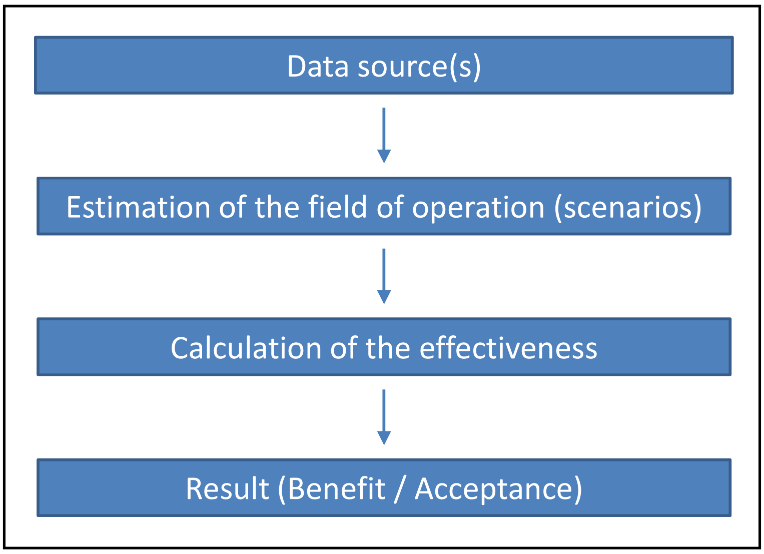

Figure 1. Principle scheme of benefit estimations for vehicle safety measures

Every main step contains various modules and methods and will be described in the following paragraphs.

Data source(s)

The basis for a reliable evaluation of any safety measure is the selection of appropriate data. Depending on the desired reliability of the entire process, the used data should meet several requirements. The most important are:

- representativeness (sample criteria of the data)
- quantity (e.g. number of accidents and/or situations)
- level of detail (available parameters)
- currentness
- availability
- accuracy

In the field of vehicle safety, national statistics have the advantage of being representative. However, the level of detail is comparatively low. On the other hand side, in-depth accident databases mostly contain very detailed information. Their disadvantage is that the data is derived from particular investigation areas with possible regional influences.

For that reason an appropriate weighting procedure should be part of the data handling. This step is important for non-representative data sources like in-depth accident databases, naturalistic driving or FOT data. Furthermore, an extrapolation to more than one country seems to be important because the majority of car manufacturers is selling their products in many markets. For that reason, the “data source” box also contains an extrapolation module. Such a module is exemplarily used in the Euro NCAP Advanced Award Protocol, where the accident numbers out of GIDAS are extrapolated to the EU-27.

Another challenging fact is the continuous change in the traffic and accident scenario. Fortunately, the most European countries show decreasing numbers of fatalities. However, historical accident and traffic data cannot easily be used for longer forecasts because everything is changing over time: traffic and mobility, the vehicle fleet, population (demographic change), infrastructure, laws etc. Especially the current equipment and development of active safety systems will strengthen these trends. The mentioned aspects can/should be addressed by further weighting processes if needed.

The following picture gives an overview about the first step (Figure 2).

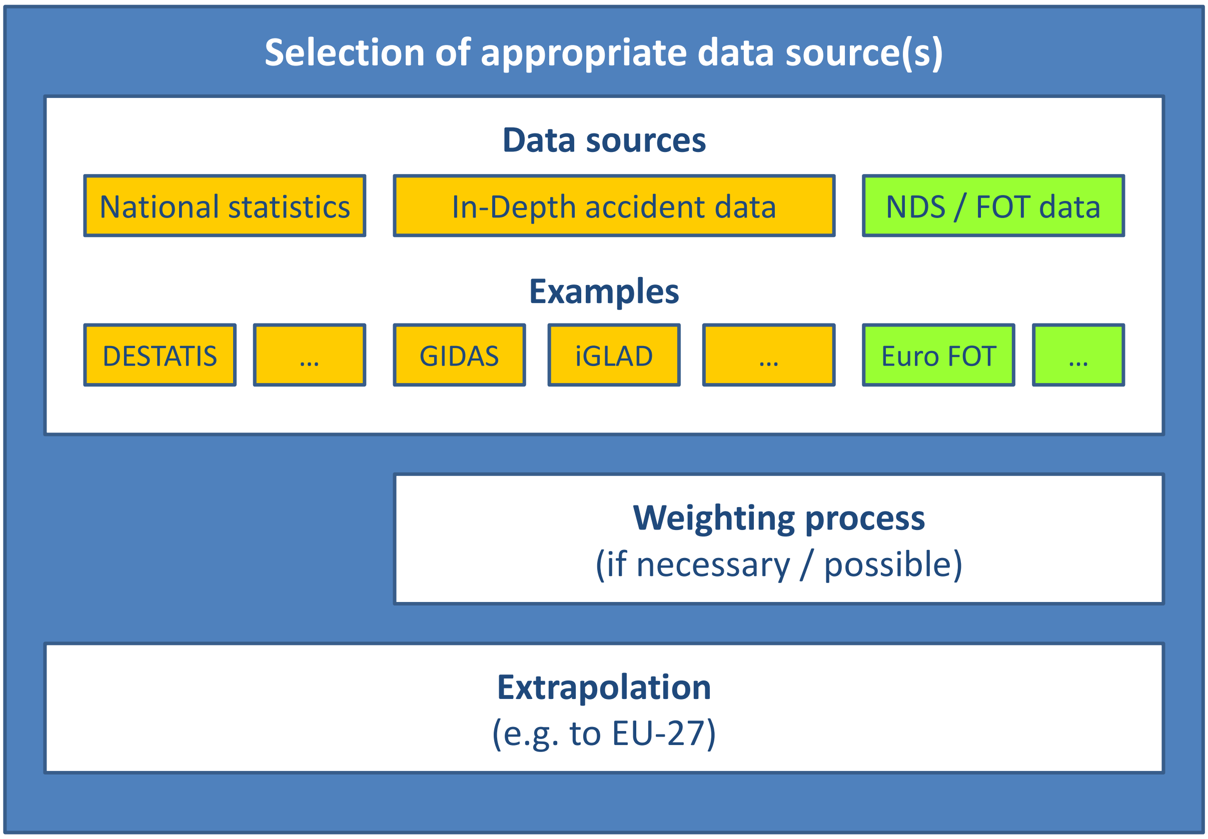

Figure 2. Content of the Data source box

Field of operation / Scenarios

Usually the benefit of a measure can be described as the product of the field of operation and the effectiveness (level of efficiency). In the second part of the benefit estimation, the field of operation is estimated. It is defined by all situations and scenarios in which a system or measure should generally act. For passive systems these are mostly certain collision types (e.g. frontal impact) whilst the system of active safety systems are certain situations (normal and critical ones). However, the field of operation is not depending from particular system specifications. As an example, the field of operation of a Lane Departure Warning (LDW) system is described as the sum of all unintended lane / road departures. The actual benefit of such a system in the real traffic scenario is limited by several circumstances that are grouped to the effectiveness.

These are for example the presence and condition (soiling, snow coverage etc.) of lane marks, the angle of lane departure, condition (e.g. soiling) of the sensors and also the reaction of the driver (depending on the HMI).

Mostly, scenario catalogues are used for the definition of the field of operation. One frequently used catalogue is the HUK Accident type catalog which contains nearly 300 different critical situations. As mentioned above for the LDW system, the field of operation can also be easily described by words. The real challenge is to identify these situations out of accident databases, NDS or FOT data. Mostly, the published data of national traffic accident statistics are not sufficient enough to make appropriate estimations of the field of operation.

Furthermore, it is important to consider the fact that one critical situation or accident can be in the field of operation of many safety systems. One example: An intoxicated driver leaves the road unintentionally, reacts with too hard steering (oversteering) and finally, skids against a tree. This case will be in the field of operation for several systems like alcolock, Lane Departure Warning (LDW), Electronic Stability Control (ESC) and several passive safety measures (e.g. airbags, belt pretensioner etc.). In such cases, the chronological order of system activation is important to avoid the overestimation of benefits.

One the one hand the estimation of the field of operation is used to identify relevant situations and/or accidents where systems are able to act. On the other hand, it gives a factor that is finally used to calculate the benefit of a system in the entire accident scenario. As an example, the maximum possible benefit of all active and passive safety measures for passenger cars in fatal car-to-bicycle accidents is below 50%, because all other fatally injured cyclists died in single accidents or collision with truck, trams, busses, PTW and other participants. Furthermore, the field of operation of forward looking safety systems has to be further reduced by excluding all cases where the ignition was not switched on (e.g. parking vehicle) or the cyclist collided with the rear end of the passenger car.

Calculation of effectiveness

In this part of the benefit estimation the actual system or system combination is evaluated. Therefore, different tools and methods are available. The challenge is to identify and to use appropriate tools depending from the system itself. In the field of vehicle safety a large variety of safety measures are already available on the market or become currently developed. Due to the complex interaction between the human (driver, pedestrian, occupant), the machine (vehicle) and the environment the benefit estimation is challenging, especially with regard to active safety systems that possibly avoid or mitigate accidents.

Therefore, the toolbox was structured into the three levels of the Haddon Matrix (Driver / Vehicle / Environment). Furthermore, the action/performance of safety systems in different phases of the situation should be considered. Thus, a differentiation between the pre-crash phase and the crash/post-crash phase was done.

The main goal is to model the behavior/action/condition of the driver and the vehicle in every phase of the situation/accident. Therefore, different methods can be used. In general, all available tools were categorized into three main groups of tools:

- Simulation tools
- Statistical approaches / methods
- Estimation

The combination of the three levels of the Haddon Matrix with the different phases of the situation and the three tool groups allows a categorization of available methods for the benefit estimation of vehicle safety measures. The following figure gives an overview about the toolbox for the calculation of benefit.

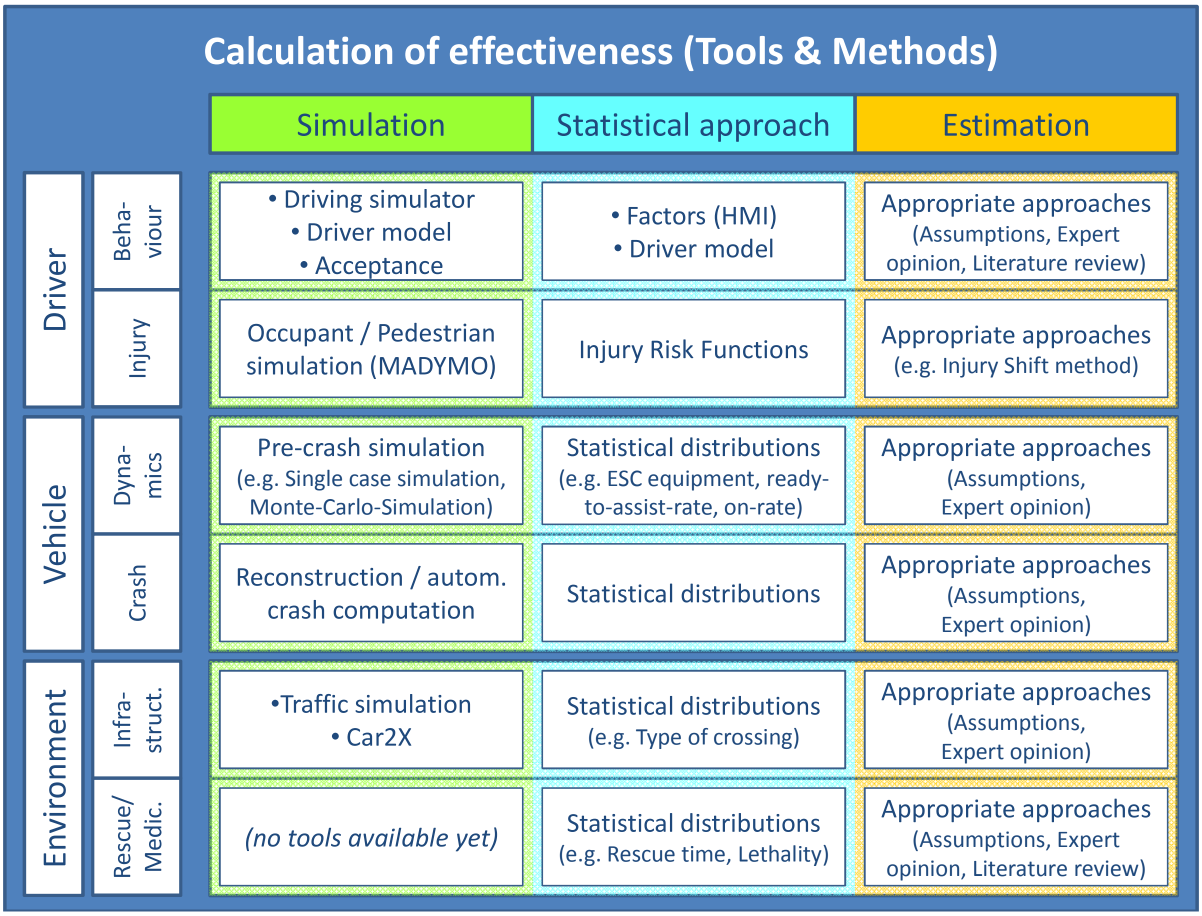

Figure 3. Toolbox for the calculation of effectiveness

In the field of simulation a lot of methods are available to model the single influences in traffic and/or accident situations. Mostly, appropriate software is already available (e.g. reconstruction programs to reconstruct/simulate the crash, simulation tools for the pre-crash simulation of single accidents). It can be assumed that these tools are more accurate than the majority of statistical methods or the estimations. The advantage is that the performance of safety systems is mostly analyzed by a case-wise simulation (often automatically done for thousands of datasets). So, the particular circumstances of single situations can be considered (see example below).

Statistical methods are often used if simulations are either not possible (e.g. due to missing models) or too effortful (e.g. costs). One example is the modeling/simulation of injuries. Although the existing models become more and more realistic and a lot of validation work is done it is still not possible to make robust predictions of the injury severity of persons in traffic accidents. This is not surprising due to large amount of factors that influence the actual injury outcome (e.g. for pedestrians: collision speed, impact points, vehicle model, age, height, gender, pre-existing illness, clothing, muscle tension, secondary impact etc.). For that reason, statistical approaches are useful to evaluate the effect of safety measures on the basis of existing data (like real accident databases). In case of the prediction of injury severities Injury Risk Functions are used as appropriate tool. However, the disadvantage of statistical methods is that particularities of single cases are not longer considered.

Finally, there is a box called estimations. These are approaches where either no simulation or statistical method is possible/available/useful, where the effort should be consciously limited or where data is missing As an example, nobody can predict the expected misuse rate of an alcolock system (e.g. by letting other people blow into the device). Here, assumptions or so-called expert opinions have to be used. In some cases, the accuracy of such estimations is rather good (depending on the experience of the estimator). Mostly, different tools have to be linked to calculate the effectiveness of a system. It is also possible that some boxes are not necessary (e.g. the environmental aspects).

EXAMPLES

Finally, the process of a benefit estimation should be displayed exemplarily with a current safety system. In the example alternatives methods in different tool boxes with different levels of accuracy and effort are mentioned. Additional explanations are given if necessary.

The example system is an emergency braking system with a radar based detection of possible collision partners and a warning function. Thus, it will not react on pedestrians and probably not on bicycles what has to be considered in the field of operation. Many of these systems combine a driver warning (optical, haptical and/or acoustical) with an autonomous braking action if the crash cannot be avoided and/or the driver did not react to the warning.

Several tasks will occur during the estimation of effectiveness. The most important are:

- Modeling of the driver behavior/reaction due to the warning function (at a certain TTC) → knowledge about driver behavior necessary (including misbehavior)
- Evaluation of the changed crash constellations due to the driver reaction and/or the autonomous braking → new crash parameters like collision speed, Δv, impact point (e.g. involvement of passenger compartment), EES, angle of impulse etc.)
- Estimation of the radar system and the involved algorithms depending on the visibility of the collision partners, systems latencies, geometrical characteristics of the radar sensor(s) etc.
- Prediction of the expected injury severity of all involved occupants due to the changed crash parameters

The following figures show the single areas of the tool box with alternative methods for the single tasks within the benefit estimation of the example safety system. In Figure 4 the methods for the driver behavior and injury prediction is shown. For many active safety systems the driver plays an important role because the vehicle tries to communicate with him by optical, haptic or acoustical information. Thus, the driver has to perceive this information and he should react in an appropriate way. However, he will do this (or not) depending on his individual reaction time and he will also react individually (steering moment, braking with different intensity, accelerating etc.). The modeling/description of this behavior is very challenging because of the numerous influencing parameters (e.g. age, gender, experience, drowsiness and attention of the driver as well as the type/performance of the HMI). The use of driving simulators is a good method to do research on this topic; however, it is mostly very expensive and needs a lot of time if many study participants should be considered. Therefore, statistical approaches or even estimations can help to reduce costs and time.

Later in the evaluation process the injury severity has to be predicted if the safety system was able to mitigate the crash severity. This is done with Injury Risk Functions because there are no simulation models available yet that can predict the overall injury severity.

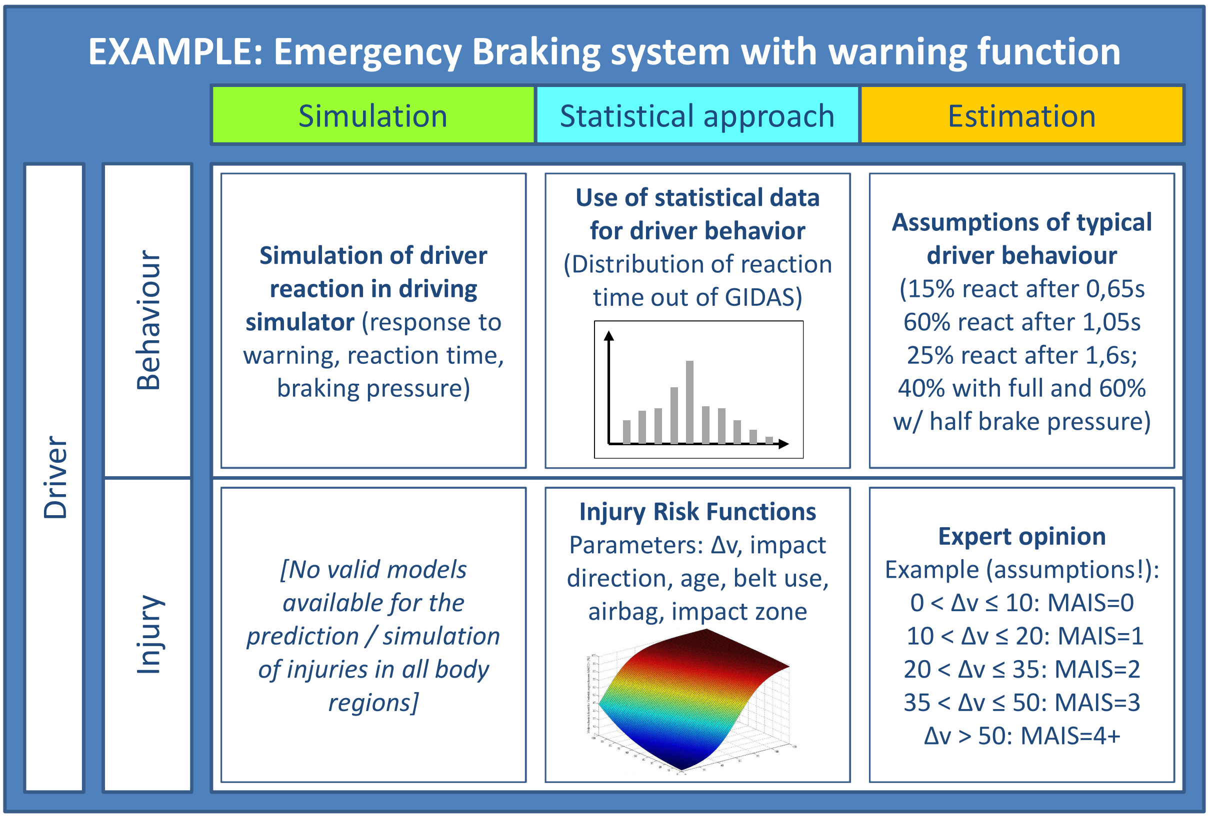

Figure 4. Application of the tool box for the example safety system (Driver box)

In the next picture all vehicle and system related actions are analyzed. Especially the evaluation of the system functionality in different situations and scenarios is a substantial part of robust benefit estimations. Therefore, simulation tools seem to be the best way as they can consider both the actual system characteristics and particularities of single cases (like view obstructions, weather/visibility, velocities, road surface etc.). Here, a linkage to other development tools is also possible (e.g. Hardware-in-the-loop).

The simulation of the system functionality results in the knowledge, which situations and/or accidents have been avoided, mitigated/changed or remained unchanged. For "simple" accident situations like car-to-pedestrian accidents or head-on collisions (longitudinal traffic) the simulation result can directly be used for the effectiveness calculation by Injury Risk Functions. For more complex situations, especially accidents in crossing traffic or skidding accidents, another step is necessary to predict the consequences of the mitigation. Due to the activation of autonomous braking systems the crash constellation will change. The equipped vehicle has a changed collision speed and due to the deceleration the collision partner is hit later, leading to another impact point. Finally, many collision parameters will be changed compared to the original accident (delta-v, EES, collision speed, impulse angle, impact point). Therefore, the new situation / crash constellation has to be reconstructed again. This can be done manually by using reconstruction programs like PC-Crash® (very high effort) or by automated crash computations (more effective, but extremely challenging).

For the chosen example of an autonomous braking system with warning function, the last box (infrastructure & rescue) is not relevant due to the fact that no interaction with the infrastructure (e.g. Car2X-communication) has to be considered.
Furthermore it is assumed that the post-crash phase (emergency call, rescue, medical treatment etc.) remains unchanged.

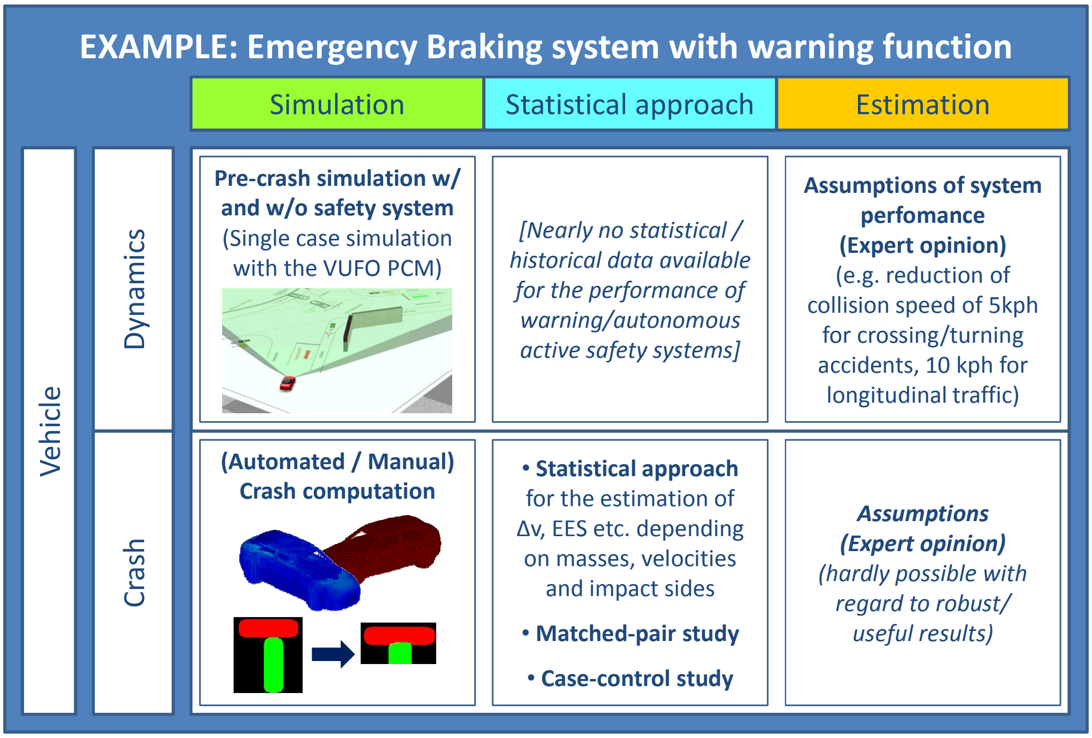

Figure 5. Application of the tool box for the example safety system (vehicle box)

The entire process for the calculation of the system effectiveness is shown in Figure 6. Nearly every active and passive safety system can be handled like the example. Depending on the system characteristics, different data sources and methods have to be used.

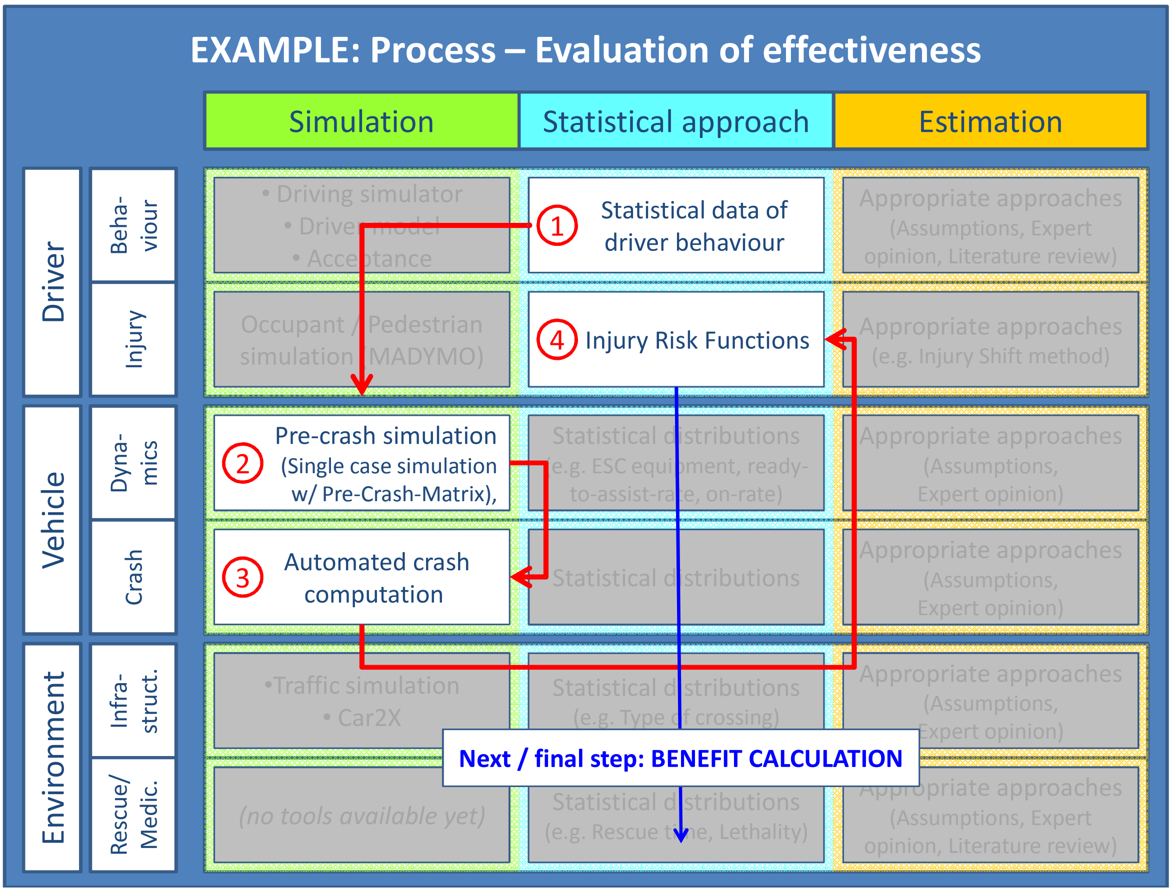

Figure 6. Process of effectiveness calculation (example)

At the end of this step there is a result out of the effectiveness calculation. Mostly, these are numbers of reduced seriously or fatally injured persons, numbers of avoided and mitigated accidents or just percentages of system activation. In the last step, the overall benefit is calculated.

Result (Calculation of Benefit / Acceptance)

Finally, all information about the data sources, representativeness, field of operation and effectiveness are linked with each other to draw a conclusion about the benefit or acceptance of a safety system. It has to be stated that the benefit is mostly oriented towards the accident scenario and thus, relatively easy to estimate. For acceptance issues the driver plays an important role due to his individual awareness of critical situations. Some drivers will need and accept assistance in an early phase of a critical situation whilst other drivers will not perceive the same situation as critical anyway. Here, a lot of research has to be done in future, involving different experts of engineering, psychology and medicine.

In the last step, the benefit of a system (or a system combination) can be further qualified, for example by calculating the robustness by doing statistical variations or tests.

In general, the term “benefit” is not clearly defined in the field of vehicle safety. However, some usual metrics are commonly used to describe the benefit of a safety system. These are:

- number/proportion of reduced fatalities/seriously/slightly injured persons
- number/proportion of addressed/mitigated/avoided accidents and/or critical situations
- reduction of economic costs

These figures can be further used to compare the benefit with the costs of a safety system (for development, testing, production, maintenance, marketing etc.). Additionally, comparisons between several systems or system configurations can be done with the presented method.

It has to be considered that some safety systems achieve a high level of effectiveness (within their field of operation) but the field of operation is comparable small (e.g. a system which effectively avoids wrong-way driving). In general, it is very challenging today to build a single safety system that is able to decrease accident and fatality numbers substantially. One reason is that the accident scenario is multifaceted. Furthermore, the effect of many technical measures is limited to special situations and/or vehicles and the market penetration of vehicles equipped with modern safety system is mostly increasing slowly.

SUMMARY AND OUTLOOK

The traffic accident research institute (VUFO) has a lot of experience in the evaluation of active and passive safety measures for vehicles. Thus, all available und useful methods have been implemented in a toolbox. This toolbox allows a standardized benefit estimation process for technical safety measures. Furthermore, this scheme can also be used for the evaluation of systems concerning acceptance issues, if appropriate data is available. The tool box was already used for the estimation of safety systems in projects like KO-FAS, sim^{TD} and aktiv. Furthermore, the benefit estimation within the Euro NCAP Advanced Award process (Phase 1 & 2) can be done with the presented tool box. Finally, lots of safety systems have been analyzed regarding effectiveness in collaboration with manufacturers and suppliers.

There are of course some limitations that should be considered. The first is that the toolbox is focusing on (technical) vehicle safety systems. It is hardly possible to adapt the methodology to all other measures in the field of prevention, enforcement or education.
In future activities the tool box should be further developed by adding additional information concerning accuracy, thresholds and robustness of the results. In addition, the implementation of other data sources is planned, especially for the evaluation of acceptance.

THE USAGE OF SMARTPHONES FOR RECORDING ACCIDENTS AND INCIDENTS FROM THE CRITICAL SITUATION UP TO THE POST CRASH PHASE

[1]Hannawald, Lars[*]; [1]Liers, Henrik; [1]von Lienen, Cäcilia
[1]Traffic Accident Research Institute at University of Technology Dresden

KEYWORDS – Real World Accidents, Incidents, Near Misses, Naturalistic Driving Data, Driving Behavior

ABSTRACT –
The changed focus in vehicle safety technology from secondary to primary safety systems need to evolve new methods to investigate accidents, high critical, critical and normal driving situations. Current Naturalistic Driving Studies mostly use vehicles that are highly equipped with additional measuring devices, video cameras, recording technology, and sensors. These equipped fleets are very expensive regarding the setup and administration of the study. Due to the great rarity of crashes it is additionally necessary to have a high distribution and a homogeneous distribution of subject groups. At the end all these facts are leading to a very expensive study with a manageable number of data.
Smartphones are becoming more and more popular not only for younger people. Contrary to traditional mobile phones they are mostly equipped with sensors for acceleration and yaw rates, GPS modules as well as cameras in high definition resolution. Additionally they have high-performance processors that enable the execution of CPU-intensive tools directly on the phone. The wide distribution of these smartphones enables researchers to get high numbers of users for such studies.
The paper shows and demonstrates a software app for smartphones that is able to record different driving situations up to crashes. Therefore all relevant parameter from the sensors, camera and GPS device are saved for a given duration if the event was triggered. The complete configuration is independently adjustable to the relevant driver and all events were sent automatically to the research institute for a further process. Direct after the event, interviews with the driver can be done and important data regarding the event itself are documented.
The presentation shows the methodology and gives a demonstration of the working progress as well as first results and examples of the current study. In the discussion the advantages of this method will be discussed and compared with the disadvantages.
The paper shows an alternative method to investigate real accident and incident data. This method is thereby highly cost efficient and comparable with existing methods for benefit estimation.

TECHNICAL PAPER –

Changes of technologies from passive/secondary to active/primary safety become more and more important. Due to that, also the used data will change from conventional impact und injury data to all information prior to the collision. In figure 1 the real accident database GIDAS is compared to naturalistic driving data of VUFO.

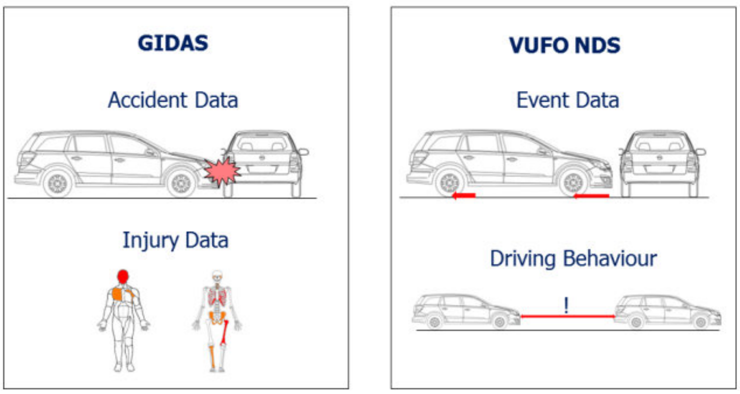

Figure 1. Comparison of accident and incident data.

If an accident occurs, the accident investigation team will be informed by the police or rescue services, so that they can investigate the real data on the spot immediately.

If an incident occurs, it will be much more difficult to get informed. A complete new method of investigation of this data is necessary to realize an interview with the participant as fast as possible. A normal event data recorder can detect crashes and strong near misses, but a video-based analysis of the situation is not applicable.

INVESTIGATION OF INCIDENTS

For that reasons VUFO began to develop a new tool for the investigation of incident data with the following boundary conditions.

- minimum installation effort at the vehicle
- (preferably) no influence to the driver
- Tool should record video-, speed-, acceleration-, gyro- and global position-data
- events should be triggered automatically
- triggering should be possible depending on position, by exceeding of physical thresholds or manually
- tool should be centrally configurable

To realize a high number of participants in a representative manner the tool should be easy to handle for consumers as well as the study operators. For an easier analysis of the data, the coding of the parameters should be analog to the GIDAS database. This also implements the simulation process analog to GIDAS with a Pre-Incident-Matrix (PIM). This allows the use of the same tools and simulation framework that already exist for real accident database like GIDAS.

In figure 2 the setup of this method is shown.

Figure 2. Setup for investigation of naturalistic driving data using smartphones.

Modern smartphones are equipped with

- camera
- acceleration sensor
- gyro-sensor
- GPS sensor
- transceiver
- CPU and memory

The described method based on an application for these smartphones which will record all the necessary parameters in a circular buffer.
For the central configuration of the application, especially for the individual triggering parameters, the method bases on a server environment as shown in figure 3.

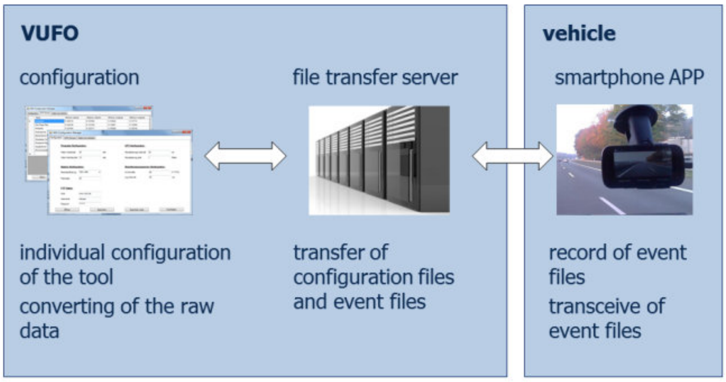

Figure 3. Server environment.

To realize a complete and independent investigation of all parameters, the tool can be configured via file transfer server. The complete data exchange is also managed via file transfer server. This guarantees that the triggered events will be as fast as possible available for the subsequent investigation of the other relevant data in relation to the event. The study participant can be interviewed concerning the event by our experts soon.

In figure 4 the basic functionality of the VUFO NDS-APP is shown.

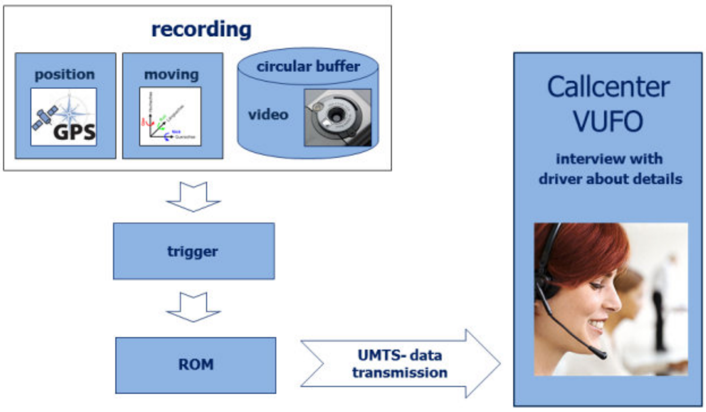

Figure 4. Basic functionality of VUFO NDS-APP.

The software records the GPS positions, all the moving parameters and the video stream in a circular buffer. If an event is triggered, a sequence of maximum 60 seconds backwards will be saved to the RAM of the smartphone. This event file will be sent via UMTS or WLAN connection to the file transfer server immediately.

In the next step VUFO will analyze this event and call back the participant to get further information, if the event is of interest for VUFO NDS.

In figure 5 the further tasks are shown.

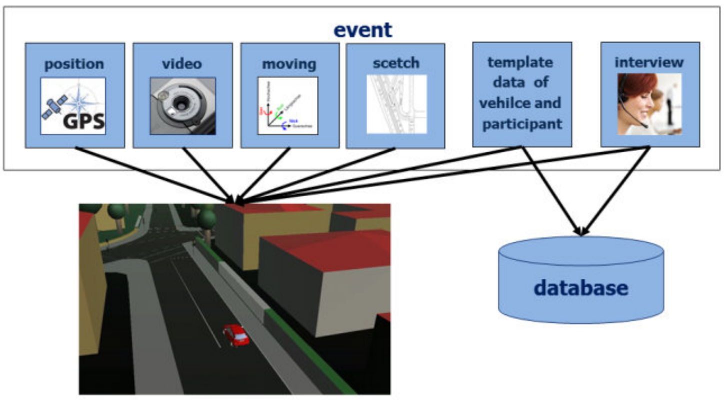

Figure 5. Further tasks for events in VUFO NDS.

The event data will be combined with a scaled sketch, all available template data of the vehicle and the participant and the interview data to a simulation of the event. This file is called Pre Incident Matrix (PIM). All parameters will be coded into the VUFO NDS database additionally.

DATA OF VUFO NDS

With the described process VUFO NDS is able to collect data in the following manner:

- driving behavior
- incidents
- accidents
- manually triggered records
- position-based records

Especially the driving behavior of the participants is important to know. VUFO NDS is using this data for an individual triggering threshold for incidents of this participant as well.

Driving Behavior

Figure 6 shows a recording of a participant with his individual comfort zone regarding longitudinal and lateral acceleration. This comfort zone is based on a record of all moving parameters for several days.

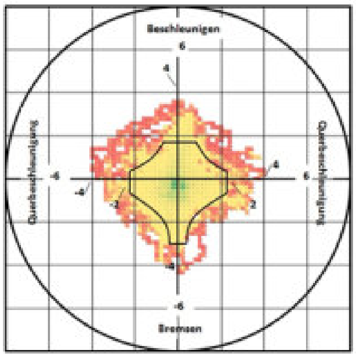

Figure 6. Recorded individual comfort zone for acceleration in x- and y-direction for the individual participant.

Incidents

Especially incidents and more or less critical situations are of interest in this project. As rare as they happen, they are very important to analyze the pre incident phase.

All warning strategies of ADAS are only appropriate when they are accepted. If acceptance could be assumed in high critical situations, it will become more and more difficult for less and uncritical situations.

Accidents

Accidents are very rare events. Only every 500.000 km an accident will occur. Nevertheless if an accident happens, the VUFO APP will record all the relevant parameters prior to the crash. These data could be used by experts to proof the innocence of the participant or at least provide data similar to an EDR.

Manually triggered records

Not all situations of interest can be triggered by exceeding of a moving parameter or by passing of GPS positions. In that case the participant can trigger an event manually.

Position based records

Especially for accident hotspots it will be of high interest to record individual sequences by passing the spot. These records can be analyzed via video and moving parameters. In figure 7 a special analysis regarding loss of control accidents on an accident hotspot is depicted.

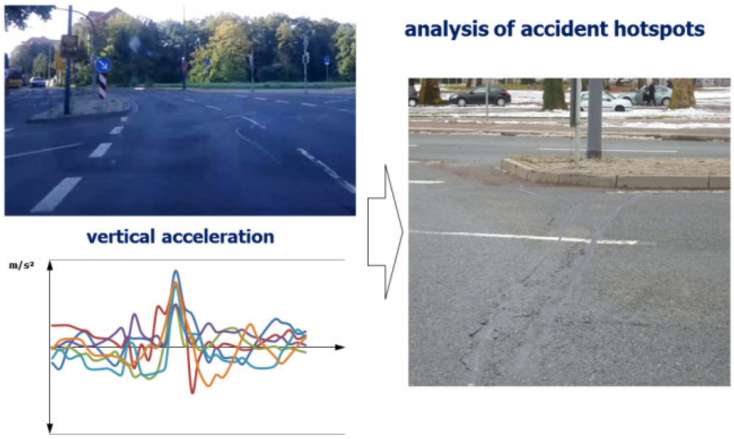

Figure 7. GPS position based accident hotspot recording.

CONSUMER BENEFIT OF VUFO NDS

Event Data Recorder

For the consumer and study participants of this project the VUFO NDS APP will work as a normal event data recorder with additional video information. (see figure 11) This data could be used by experts to proof the innocence of the participant.

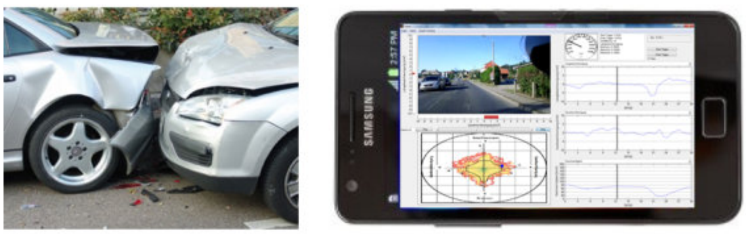

Figure 11 VUFO APP as event data recorder

A normal upgraded event data recorder costs around 1000€ while the VUFO NDS APP is free of charge.

Hazard Warning

The VUFO NDS APP could also be used as a hazard warning due to different daily driven situations. Figure 12 shows show some of these possibilities.

Figure 12. Hazard warning functionality.

The warning threshold could be easily adjusted be using the driver behavior results as described before.

Economic Driving

Economic driving is becoming more and more important. VUFO NDS APP could help to drive as economically as possible by measuring the real situation and comparing it to the average or most effective one in the same situation. This will help to reduce unnecessary expense. Figure 13 shows the principle setup.

Figure 13. Economic driving functionality.

CONCLUSIONS

Detailed information about the pre-crash or pre-incidence phase needs to be investigated with new methods. The paper shows an application for smartphones which is able to detect critical scenarios as well as recording moving parameters of the participant.

At the Accident Research Unit VUFO, this app is used to build up a naturalistic driving database near to existing real world accident databases (e.g. GIDAS).

The comparability to this database guarantees the use of the same methods and simulation tools for all future users.

The VUFO NDS APP could also be used for the consumer in terms of event data recorder for crashes and warnings and information about hazard and economic driving.

Investigation of the accident avoidance potential of front-camera-systems with lateral field of vision in vehicle-bicycle accidents on the basis of the GIDAS accident database

Author: Dipl.-Ing. Uli Uhlenhof

Verkehrsunfallforschung an der TU Dresden GmbH
Semperstraße 2a
01069 Dresden

Email: uli.uhlenhof@vufo.de

Tel.: +49 (351) 43898931

The Traffic Accident Research Institute at University of Technology Dresden investigates about 1,000 accidents annually in the area around and in Dresden. These datasets have been summarized and evaluated in the GIDAS (German Accident In-Depth Study) project for 13 years.

During the project it became apparent that the specific traffic situation of a covert exit of a passenger car and an intersecting two-wheeler involves a high risk potential. This critical situation developes in a large part due to the lack of visibility between the driver and the intersecting bike. In this work the accident avoidance potential of front camera systems with lateral field of view, which allows the driver to have an indirect sight into the crossing street area will be studied.

The following points will be discussed in the study:

• Existing systems and their functionality

In the first step, the existing systems will be presented in a short overview.

• Identification of the accident avoidance potential

On the basis of the Dresden-GIDAS accident dataset 2009/2010 relevant accident situations will be found. Furthermore, the vehicles involved will be identified. A classification of the accident locations is required.

• Investigation of the critical situation

The critical situations will be studied in more detail. In this part of the investigation the different vehicle types and their specific field of view at different accident sites will be shown. The relationship between speed and avoidance potential will be illustrated.

• Accident avoidance potential

This last step will analyze how the accident avoidance potential of front camera systems with lateral field of view could be estimated.

1 Motivation

The GIDAS accident-investigation team investigates traffic accidents with injured persons regardless of the form of the participation or injury severity. The proportion of accidents involving several vehicles and at least one cyclist has the dimension 34% of all recorded accidents in the GIDAS database.

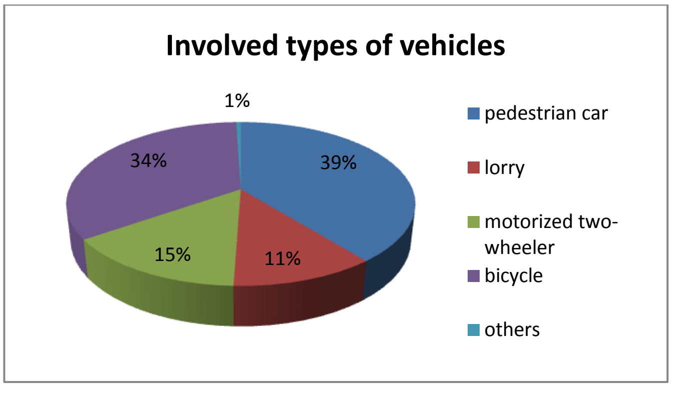

Figure 1: Involved types of vehicles
(Source: own illustration)

In nearly all cases involving a cyclist the cyclist was injured exclusively. The percentage of severely injured or killed cyclists in these accidents was 20.7% of all injured cyclists.

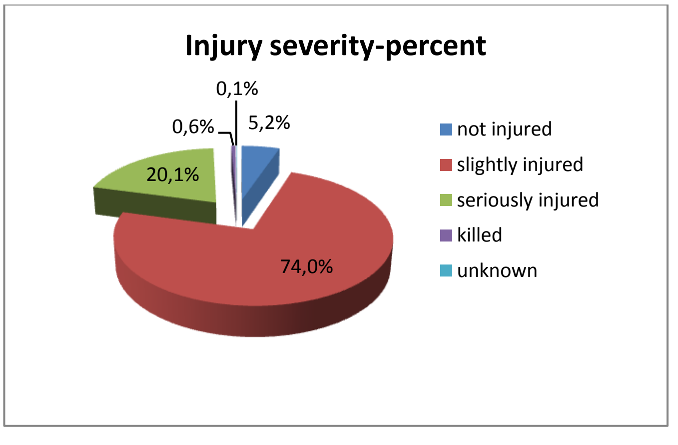

Figure 2: Injury severity in percent
(Source: own illustration)

It is therefore clear that many injuries to cyclists can be prevented by avoiding the critical situation between a motorized vehicle and a bicycle first and foremost.

Over the accident survey, a special type of accident emerged. It involves the re-occurring situation of an intersecting vehicle from a land access, driveway or a road at one site and on the other site a bicycle on a bicycle way or pavement. The view of both accident opponents to each other is strongly obscured.

This difficult conflict-situation is almost inevitable for the driver because he constructively is behind the line of sight. The equipment of cars with vision systems that produces an insight into the intersecting roadway behind the obstruction could be a solution for avoiding this accident situation. The present study investigated on the basis of two selected Dresdner-years GIDAS accident database, how the accident occurrence could be changed by the behalf of these vision systems.

2 Existing systems

In principle, two different systems are distinguished: one-or two-camera systems. Both image views are shown in different ways, depending on various systems of manufacturer and model series of the vehicles. The possibilities are wide-ranging, from simple pictorial representation on a screen in the integrated navigation system to intelligent work-up in Birds-view representation.

Figure 3: Example for a split-screen display in the vehicle
(Source: own illustration)

2.1 One-camera-system

As the name suggests, only one camera is used for detection. The camera is located in front of the vehicle, usually in the emblem or on the radiator grille of the vehicle. Thus, an undisturbed field of view is possible to the right and to the left. In order to realize the angle of deflection, a prism in front of the camera is installed.
The system is structurally relatively simple and is relatively common, therefore it is very widespread under the vision systems.

The disadvantage is the limited field of view caused by the opening angle of the prism.

Furthermore, it must be noted that in some systems, a protective hood is attached, which closes the unit at standstill or from speeds of over 15km/h. Thus, the applicability of the system is limited to the range of speeds up to 15km / h.

Figure 4: One-camera-system, integrated in the emblem of the car
(Source: http://www.adac.de/_ext/itr/tests/Autotest/AT1226_Toyota_Corolla_Verso_18_Executive/Toyota_Corolla_Verso_18_Executive.pdf)

2.2 Two-camera-systems

In this technical solution, two cameras are installed. They are located either directly behind the plate or in the front fenders or bumper covers. Thus an almost unlimited field of view allows to the side. A disadvantage is the installation in the fenders. The vehicle must move already 30 to 40cm behind the obstruction out of the crossing way to give a view-access to this road area.

Figure 5: Two-camera-system
(Source: http://www.7-forum.com/bild.php?bild=news/2010/6er_cabrio/p90068743-b.jpg&title=BMW%206er%20Cabrio%20(F12)
,%20Felge,%20Side-View-Kamera%20im%20Kotfl%FCgel&cpy=bmw)

Due the further extension of the one-camera-systems the following study refers only on these systems.

3 Identification of the accident avoidance potential

In the next step, the critical accident situations should be identified. Basis of the investigation should be two selected Dresdner years of the GIDAS database. The investigated accidents of the years 2009 and 2010 are complete and plausible available.
In the GIDAS accident database both technical as well as medical and statistical data are collected.

3.1 Type of accident

Essential information of an accident is the so-called critical situation. This critical situation is identified and categorized in the database according to the German accident type system of the General Association of German Insurers (GDV) [1]. For the identification of the type of accident the collision types or guiltyness are not interesting, only the conflict situation is shown by the type of accident.
The type of accident is categorized in different basic situations. Because of the intersecting routes of the vehicles involved, the category "bending-crosses" assigned.
In the German traffic law vehicles from driveways and intersections which cross the pavement or bicycle ways have to respect the right of way. That´s way in these situation is a privileged bicycle. The direction from which is crossed, does not matter. Walking and biking trails are also categorized as special ways.
This situation is represented by the type of accident number 341 and 342.

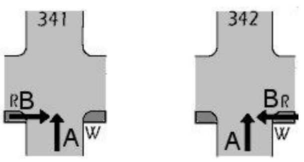

Figure 6: Type of accident 341 (left) and 342 (right)
(Source: GIDAS Codebook 2014)

The share of this critical situation of total accidents is overall in GIDAS in 7%, 1558 accidents, in the two years in Dresden at 5%, 96 cases.

3.2 Vehicle participation and visual obstruction

Furthermore, only accidents will be used, which have occurred between a vehicle (car, truck) and a bicycle. Because of a bicycle-bicycle accident 95 cases are still available for the evaluation.

Finally, the sight situation is assessed at the scene. In the database GIDAS a detailed documentation of the accident-scene and the driven roads takes place. An important detail is the evaluation of a visual obstacle that has influenced a direct view of the accident opponents to each other (or even in single vehicle accidents the view of the driver on the road).
After evaluating the situation view 60 accidents were available for evaluation.

[1] GDV has emerged among others out of the liability insurance, personal accident and motor insurers association (HUK). The HUK created the accident-type-system originally.

4 Investigation of the critical situation

4.1 Vehicle shape

In order to assess the critical situation and the effectiveness of a camera system, the vehicle shape is included in the investigation. The main reason for this safety-increase is the distance from the front of the vehicle to the original viewing position of the driver. Suppose here is, that the driver can see now into the crossing direction with a camera system from the position of the steering wheel-the originally view position. This distance could be called as the safety-increase by using a camera system.

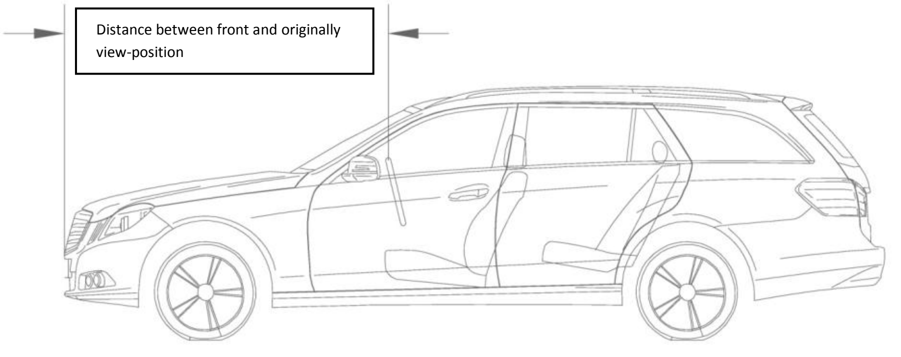

Figure 7: Distance between front an originally view-position
(Source: own illustration)

4.2 Initial velocity

In the GIDAS accident analysis, all accidents are reconstructed, i. e., the most likely progress of the accident will be presented. Important elements of reconstruction are the determination of the collision and initial speeds.
As described in "2.1 One-camera-systems", systems are currently applicable only up to a speed of 15 km/h. That´s why the initial speed of the involved pedestrian cars and heavy good vehicles (lorries, busses) have to be investigated. In the reconstruction were found 15 cars with more than 15km/h initial speed. In these cases, the camera system as described would not be effective. For these cases could not be detected a prevention-potential.

For the remaining 45 accidents the safety-potential is analyzed.

5 Accident avoidance potential

5.1 Spatially avoidable

The spatial preventability is examined whether an accident participant his vehicle in time may bring to a stand before the collision point by maintaining the required speed and reacts in the same way. Here this calculation is made only for the driver of the motor vehicle. The response of the cyclists is assumed to be the same.

"An accident is then spatially avoided if the distance between the reaction and the collision, the distance to avoid the crash, is greater than the stopping way out of permitted speed." [3, p. 293]

Basic assumption should be that all involved drivers use the camera system and react accordingly.
As a further assumption a mean braking deceleration of a mid-size car on dry pavement (asphalt) is assumed.

$$a_b = 8\frac{m}{s^2} \qquad [5.1.1]$$

Adding the routes during the reaction time $\mathrm{d_r}$ and during the braking period $\mathrm{d_b}$ we obtain d_a the distance to avoid the crash.

$$d_a = d_r + d_b \qquad [5.1.2]$$

If the collision speed and braking deceleration a_b are known, the initial speed v_0 could be calculated.

$$v_0 = \sqrt{{v_K}^2 + 2 * a_b * \ d_b} \qquad [5.1.3]$$

If the speed during the reaction-time stays constant, the distance to avoid the crash is:

$$d_a = \frac{{v_0}^2 - {v_K}^2}{2 * a_b} + v_0 * t_r \qquad [5.1.4]$$

The reaction time could be divided into seven distinct sections. The primary reaction time includes the perception time, the detection time and the decision time. Then the motoric phase, the time for the implementation, the application period and the swelling time follow.
Reaction times fluctuate between 0.4 s and 1.6 s. They will be influenced by the driver's attention, the intensity of the response prompt and view payments within peripheral events. To create comparable results a total reaction time of 0.7 seconds is assumed here in every case. This assumption is justified because the driver expects the other road users and thus has a low response time.

$$t_r = 0{,}7s \qquad [5.1.5]$$

From this it follows, that the way of the reaction d_r with a constant initial speed v_0 and the assumed reaction time t_r could be calculated with:

$$s_r = \frac{v_0}{3{,}6} * 0{,}7s \qquad [5.1.6]$$

After that the measured distance front-originally view d_{afs} will be added to s_a. As a result we get the distance to avoid the crash s_{a_K}, which is available with a lateral front-camera-system.

$$s_{a_K} = s_a + s_{afs} \qquad [5.1.7]$$

By the help of the distance to avoid the crash s_{a_K} the maximum speed could be calculated, where the vehicle had come to a halt in front of the originally collision point. This is the maximum speed for the spatially avoidance.

$$v_{R_{max}} = -a_b * t_r + \sqrt{(a_b * t_r)^2 + 2 * a_b * s_{a_K}} \qquad [5.1.8]$$

This calculation was done for all 45 vehicles. A total of 13 accidents are spatially avoidable. This means that in 13 cases the motorized vehicles with a front camera system would come to a halt with an adequate reaction of the driver before the initial collision point.

5.2 Temporally avoidable

In the following, the temporally avoidance of the relevant accidents is examined. Here it is checked whether it would have been possible to reach the point of collision due to the previous review so much later that the cyclist would have already left the collision point.
For this purpose the distance to avoid the crash is divided into several sections. First, the road is determined that the driver travels during the reaction time. Due to the requirement that the motor vehicle driver expects a forthcoming event, a response time of 0.7 seconds is assumed again.

$$t_r = 0{,}7s \qquad [5.2.1]$$

The reaction distance d_r is calculated out of:

$$d_r = \frac{v_0}{3{,}6} * 0{,}7s \qquad [5.2.2]$$

Subsequently, the path is computed which is covered in the swelling time. Here a linear increase of the brake pressure is assumed and thus determines a delay during the swelling time of 4 m/s ². This corresponds with $\frac{a_b}{2}$. It is further assumed a swelling time of 0.3 seconds.

$$a_s = \frac{a_b}{2} = 4\frac{m}{s^2} \qquad [5.2.3]$$

$$t_s = 0{,}3s \qquad [5.2.4]$$

The part of the distance, which belongs to the swelling time, could be calculated with:

$$d_s = a_s * t_s^{\ 2} \qquad [5.2.5]$$

The entire distance to avoid the crash available to the driver of the passenger vehicle is calculated in the GIDAS reconstruction. It is the length of the travel time by the path of the reaction to the primary collision. This length is referred to here with d_f. In order to show the usefulness of the front camera system to the travel time by the path d_f will be added the distance front-originally view d_{afk}. The result is d_{FK}.

$$d_{FK} = d_f + d_{afk} \quad [5.2.6]$$

By the known length of the distance to avoid the crash, the available braking distance $d_b$can be calculated.

$$d_b = d_{FK} - d_r - d_s \quad [5.2.7]$$

The available time for the braking of the vehicle obtained from the following formula:

$$t_b = \sqrt{\frac{2*d_b}{a}} \quad [5.2.8]$$

The time available for the entire maneuver time is then calculated out of

$$t_g = t_r + t_s + t_b \quad [5.2.9]$$

To calculate the maximum speed for temporal avoidance that time has to be determine, which requires the cyclist for clearing the point of collisiont_{cl}. The vehicle width of motorized vehicle d_v and the speed of the cyclist v_c affect the clearance time. Here, it is assumed that the cyclist continues its travel at a constant

$$t_{cl} = \frac{d_v}{v_c} \quad [5.2.10]$$

The time to avoid the crash is then obtained by adding the total time it takes for the car driver to arrive at the collision point and the time it takes the cyclist for clearing the point of collision.

$$t_{avoid} = t_g + t_{cl} \quad [5.2.11]$$

With the help of these can then the maximum speed of temporal avoidance be determined:

$$v_{Z_{max}} = \frac{2*d_{FK}+\frac{1}{2}*a*t_s{}^2-a*(t_{avoid}-t_r-t_s)^2}{2*t_r} \quad [5.2.12]$$

The temporal avoidance was calculated for all investigated accidents. With this method of calculation including the use of a front camera system 10 accidents could be avoided.

As already would have been spatially avoided 2 accidents could be avoided by 60 relevant accidents in total through the use of a camera system 21.

6 Summary and conclusions

The individual case analysis has shown that camera systems with lateral field of view to each other involve a high safety potential in the specific situation of a covert visual relationship of the parties. In about one third of the examined and illustrated critical situations, these systems have the driver given the opportunity to avoid the accident. As a result of an avoided accident with cyclists participation injuries could be prevented.

But this is a single case-analysis and that's why there should be discussed the following points:

Until now, the conditions under which these camera systems are subject to high restrictions (field of view, speed), and in addition they are not yet widespread.

But an increase in the degree of distribution is expected with the increasing vehicle equipped with parking assistance systems. That means that the equipment of a car with those systems is simultaneously an advantage in traffic safety.

If one assumes that the driver is aware of the danger of the situation, it can be assumed from low speeds and thus of applicability of the systems. That means that there is a lot of work to do to improve the awareness aof the drivers for these critical situations. As a result we get a better possible application-rate of the camera systems.

The camera systems could but so far only be judged as passive assistance systems. They only transfer the image from the lateral field into the inner space of the car to any desk and there is no automatic evaluation and assessment of the situation. That means that drivers must correctly process the information and react appropriately. This has been assumed in the present case by case analysis.

Certainly current research in the field of video analysis will have an impact on the camera systems with lateral field of view. Conceivable here automated alerts and independent braking interventions in identified and defined critical situations. With such a development camera systems can make an effective contribution to accident prevention and the reduction of injuries in traffic accidents with covered lateral field of view.

Appendix

Table 1: Type of participation in vehicle-bicycle accidents in GIDAS

Participation of minimum:	Description	Number of cases	Percent
passenger car	one passenger car and no one vehicle of the following groups is involved	6662	39%
lorry	one lorry, bus or tram and no one vehicle of the following groups is involved	1928	11%
motorized two-wheeler	one motorized two-wheeler and no one vehicle of the following groups is involved	2506	15%
bicycle	one bycicle and no one vehicle of the following groups is involved	5805	34%
others	one other vehicle is involved	87	1%
unknown	unknown vehicle is involved	1	0%
sum		**16989**	**100%**

Table 2: Injury severity (official categorization) of participating bicyclists in vehicle-bicycle accidents in GIDAS

Injury severity	Number of byciclists	percent
not injured	311	5,2%
slightly injured	4417	74,0%
seriously injured	1200	20,1%
killed	36	0,6%
unknown	4	0,1%
sum	5968	100%

Table 3: Injury severity (Maximal abbreviated injury scale-MAIS) of participating bicyclists in vehicle-bicycle accidents in GIDAS

MAIS 2005	Number of byciclists	percent
0	317	5,3%
1	4464	74,8%
2	731	12,2%
3	182	3,0%
4	30	0,5%
5	20	0,3%
6	7	0,1%
9	217	3,6%
sum:	5968	100%

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Assessment of the effectiveness of Intersection Assistance Systems at urban and rural accident sites

C Zauner*, E Tomasch**, W Sinz***, C Ellersdorfer* and H Steffan****

* Project-Assistant, Graz University of Technology, Vehicle Safety Institute, Inffeldgasse 23/I, Graz, Austria
** Project-Senior Scientist, Graz University of Technology, Vehicle Safety Institute, Inffeldgasse 23/I, Graz, Austria
*** Vice Head of Institute, Graz University of Technology, Vehicle Safety Institute, Inffeldgasse 23/I, Graz, Austria
**** Head of Institute, Graz University of Technology, Vehicle Safety Institute, Inffeldgasse 23/I, Graz, Austria

Abstract

An Intersection Collision Avoidance System is a promising safety system for accident avoidance or injury mitigation at junctions. However, there is still a lack of evidence of the effectiveness, due to the missing real accident data concerning Advanced Driver Assistance Systems. The objective of this study is the assessment of the effectiveness of an Intersection Collision Avoidance System based on real accidents. The method used is called virtual pre-crash simulation. Accidents at junctions were reconstructed by using the numerical simulation software PC-Crash™. This first simulation is called the baseline simulation. In a second step the vehicles of these accidents were equipped with an Intersection Collision Avoidance System and simulated again. The second simulation is called the system simulation. In the system simulation two different sensors and four different intervention strategies were used, based on a Time-To-Collision approach. The effectiveness of Intersection Collision Avoidance Systems has been evaluated by using an assessment function. On average 9% of the reviewed junction accidents could have been avoided within the system simulations. The other simulation results clearly showed a change in the Principal Direction of Force, delta-v and reduction of the injury severity.

NOTATION

ADAS	Advanced Driver Assistance Systems
AIS	Abbreviated Injury Scale
BP	Brake Power
C2C	Car-to-Car
C2I	Car-to-Infrastructure
Delta-v (Δv)	Change in velocity
EES	Energy Equivalent Speed
GoFAST	Generic Sensor Effectiveness Assessment of Advanced Driving Assistance Systems Tool
ICAS	Intersection Collision Avoidance System
LRR	Long Range Radar
MAIS	Maximum Abbreviated Injury Scale
MD	Median
PDoF	Principal Direction of Force
SD	Standard Deviation
SRR	Short Range Radar
TTC	Time-To-Collision
v_k	Collision velocity
ZEDATU	Zentrale Datenbank zur Tiefenanalyse von Verkehrsunfällen

INTRODUCTION

On average accidents at junctions make up 37% [13, 2010b, 18] of all road accidents with injuries. Various countermeasures for junction accidents have been developed. These countermeasures could be associated to the primary (collision avoidance), secondary (mitigation of injuries) or tertiary (post-crash treatment) safety. The main causes for the high density of accidents taking place at junction are misinterpretations and inattentiveness by the vehicle drivers at cross-over points. Misinterpretation means that the situation at junctions itself is perceived by the driver, but the individual interpretation is often ranked wrong. A typical example would be the misinterpretation of other vehicle's velocities. Furthermore the complexity of junctions tends to hinder the driver of visualizing potential threats. Exemplarily the driver's behaviour "looked" but "failed to see" is mentioned. Inattentiveness refers to the distraction of the driver from normal driving tasks, which often results in extended reaction times. Driving and the parallel use of a mobile phone is mentioned exemplarily. [11, 2012, 15, 2007b]

Reviewing the main causes for junction accidents allows formulating the basic requirements for an Intersection Assistant System. By approaching an intersection the information density a driver must process increases a lot. ADAS (Advanced Driver Assistance Systems) that use a variety of sensors to check surroundings support the driver in decision-making as well as taking counter measure for accident avoidance into effect. ADAS integrate semi- as well as fully autonomous intervention strategies to avoid collision or at least mitigate injury severity. Depending on a TTC (Time-To-Collision) approach different intervention strategies use characteristic threshold values for initiation. TTC refers to the time from the first opponent detection until collision. [11, 2012]

To evaluate the effectiveness of ADAS especially ICAS (Intersection Collision Avoidance Systems) several approaches in current literature exist. Each testing environment is distinguished itself by several advantages and disadvantages.

Possibilities to evaluate the effectiveness of ICAS

Statistical evaluation

In most countries statistical data of traffic accidents is collected at a regular basis by the police. If this data includes information of active safety systems e.g. ICAS conclusions can be drawn. Due to the very young history of ICAS, the density of accident data concerning these systems is still quite moderate. Therefore statistical data provides basic information, but a detailed evaluation of ICAS is often impossible. [5, 2010a]

Driving simulator

Driving simulators offer accurate adjustability and a high degree of repeatability to evaluate a diversity of possible accident scenarios. In addition they allow system tests in early stages of the developing process. The digital surrounding generation allows a variety of driving situations and system parameters to be tested and evaluated in detail. Limitations for the driving simulator refer to the drivability of the proband, because of the restricted threat awareness (Image and movement system). Furthermore the use of driving simulators requires a high amount of effort to prosecute Hard- and Software, scenario layout and illustration of vehicles and systems. [11, 2012, 12, 2006b, 19, 2010c]

Test phases on testing ground and real road traffic

Test phases on testing ground are compared to driving simulators closer to reality. Probands drive a vehicle without restrictions regarding sight and driving dynamics. Simple test scenarios need to be developed and proven to be repeatable and reliable. These tests require a high amount of effort to be illustrated in an effective non-threatening, but for the driver subjective critical situation. [11, 2012]

Virtual pre-crash simulation

Another approach to evaluate the effectiveness of ADAS is a virtual pre-crash simulation. The reconstructed accident using a trajectory based simulation software such as PC-Crash™ guides as the baseline simulation. All of these reconstructed accidents are calculated and simulated a second time but the vehicles are equipped with ADAS. Different sensors and intervention strategies can be applied separately. This simulation is called the system simulation. The evaluation of the effectiveness of ADAS uses an assessment function comparing the baseline with the system simulation. [4, 2008b]

METHODOLOGY

The method used in this study (see Figure 1) refers to the virtual pre-crash simulation. The baseline used to evaluate the effectiveness of ICAS emanates from real accidents at junctions taken from ZEDATU (Zentrale Datenbank zur Tiefenanalyse von Verkehrsunfällen) [6, 2007a] database. The numerical simulation software PC-Crash™ is used for the reconstruction of the real accidents from ZEDATU. ZEDATU uses a retrospective accident investigation approach [7, 2006a, 8, 2008c, 2, 2009].

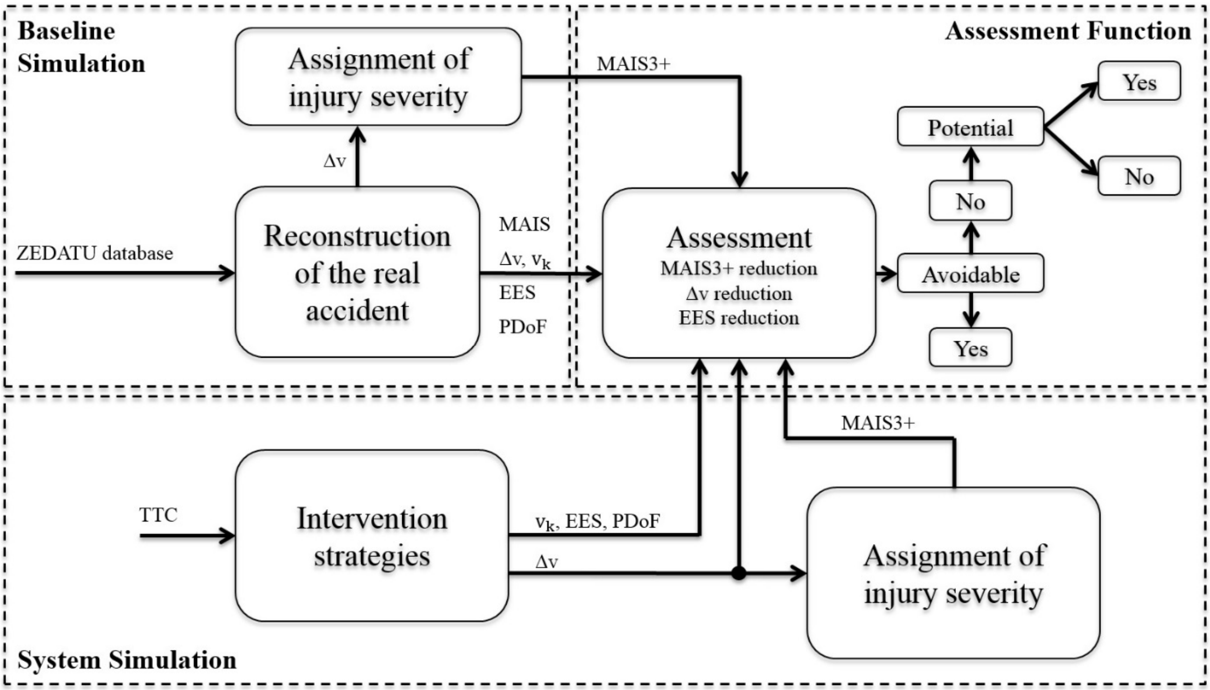

Figure 1. Virtual pre-crash simulation method

Baseline Simulation

The reconstruction includes the pre-crash phase for the involved vehicles using a forward and backward simulation. The forward simulation is used to calculate the delta-v, EES (Energy Equivalent Speed), etc. For the calculation of the crash phase the three dimensional momentum-based impact model [10, 1966b, 3, 1966a] has been chosen. This impact model allows a compromise between effort and accuracy. In the backward simulation the initial vehicle velocities and the trajectories of the participants are calculated to define the pre-crash phase. The reconstructed accidents in ZEDATU guide as the *"baseline simulation"*.

System Simulation

A backwards calculation from the impact point of approximately 5s or more is necessary to initiate a second simulation starting in the pre-crash phase. This simulation is called the *"system simulation"*. The system simulation builds up on the baseline simulation. An ICAS is now included in one of the involved vehicles. To evaluate the influence of ICAS on different vehicles, each vehicle gets equipped with ICAS in separate simulations.

To examine different ICAS with different intervention strategies the software tool GoFAST (Generic Sensor Effectiveness Assessment of Advanced Driving Assistance Systems Tool) was used. This tool allows to define specific system parameters (e.g. sight distance, angle of aperture, etc.) for the sensor as well as system manoeuvres and the TTC reaction point to initiate those manoeuvres. After defining the system parameters the system simulation can be calculated automatically within the PC-Crash™ simulation environment.

To allow a comparison of injury severity between baseline and system simulation the generic injury severity for the vehicle drivers is calculated on the basis of risk curves for the baseline as well as for the system simulation. Considering real accidents only, the injury severity for the vehicle passengers can be classified according to the AIS (Abbreviated Injury Scale) injury scale. The risk curves used for this study constitute a correlation between delta-v and the probability of a MAIS3+ injury severity for the vehicle drivers (see Figure 2). Exemplarily the results for the probability of a MAIS3+ injury severity for the vehicle driver are illustrated for a frontal collision in Figure 2. Comparing a delta-v of 60 km/h from a real accident (baseline simulation) with the delta-v of 32 km/h from a generic accident (system simulation) by using ICAS b) (see Figure 4), the probability of MAI3+ injury severity for the vehicle driver could be reduced from 98% to 24%.

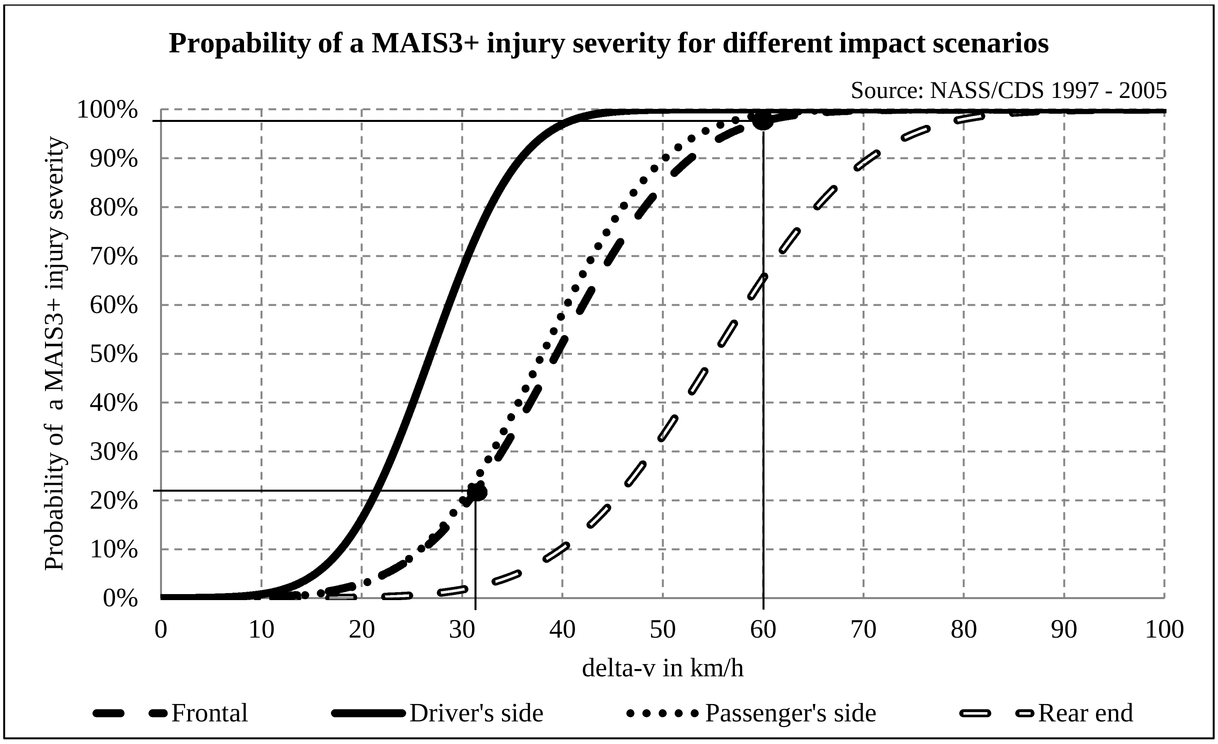

Figure 2. Relation between MAIS3+ and delta-v for the vehicle driver [14, 2011]

Sensor definition for surroundings detection

In the system simulations the vehicles have been equipped with a LRR (Long Range Radar) and three SRR (Sort Range Radar) sensors (see Figure 3). The sensors have only been implemented geometrically in the reviewed simulations. Detailed tracking and classification algorithms haven't been considered for this study. The detailed sensor parameters (sight distance and horizontal angle of aperture) are given in Table 1. Participants which enter the view cone of the sensors are identified. After a time frame of 100ms in the sensor view cone an intervention strategy is initiated in case of an appropriate value of TTC. If the detected vehicle has left the view cone at the intervention strategy initiation point, the system simulation has been aborted. It is assumed that the surroundings detection works ideal (e.g. no consideration of the material depending reflection of radar beams, no detection probabilities for different objects, etc.) and independent from external influences (e.g. weather, lightning conditions, etc.). [2, 2009, 1, 2008a]

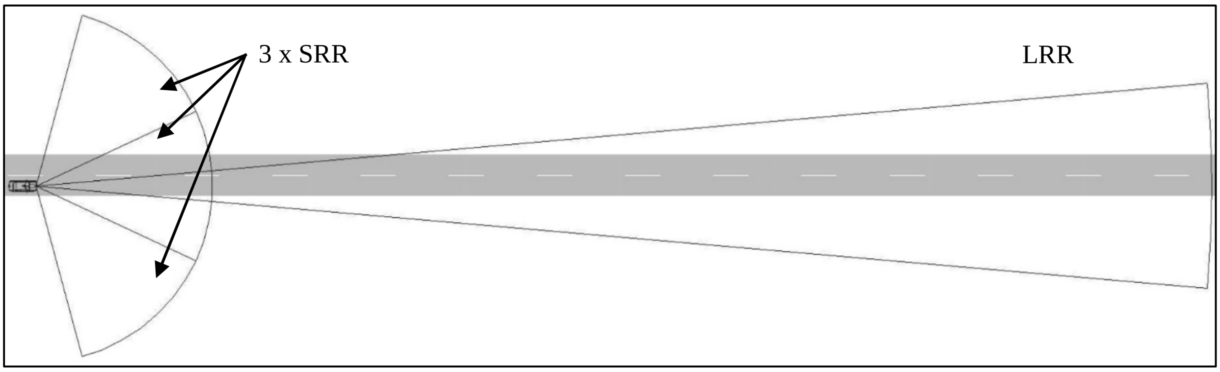

Figure 3. Sensors for surroundings detection

Table 1. Sensor parameters [16, 2006c, 9, 2008d]

Sensor	Sight distance	Horizontal angle of aperture
SRR	30m	50°
LRR	200m	10°

Examined intervention strategies for ICAS

Four different intervention strategies for an ICAS have been used and evaluated within the numeric simulation environment. For initiation, all four strategies refer to specific levels of TTC (see Figure 4).

a) **TTC = 2.6s:** It is assumed that the driver reacts with 0.8s reaction time on a warning signal (optical and haptic). After the reaction time the vehicle was decelerated with the maximum braking power without brake lag time.

b) **TTC = 1.6s:** The system starts to decelerate the vehicle with 50% of the maximum brake power to alert the driver. Again after the reaction time (0.8s) the vehicle was decelerated with the maximum brake force for the remaining 0.8s before stop or collision.

c) **TTC = 1.6s:** Again the system initiates a deceleration with 50% of the maximum brake power. In this strategy no reaction from the driver is simulated and the system keeps on braking with 50% brake force until stop or collision.

d) **TTC < 1.6s:** No reaction from the driver is assumed! When the vehicle reaches the TTC=0.8s limitation the system autonomously initiates an emergency braking manoeuvre until stop or collision.

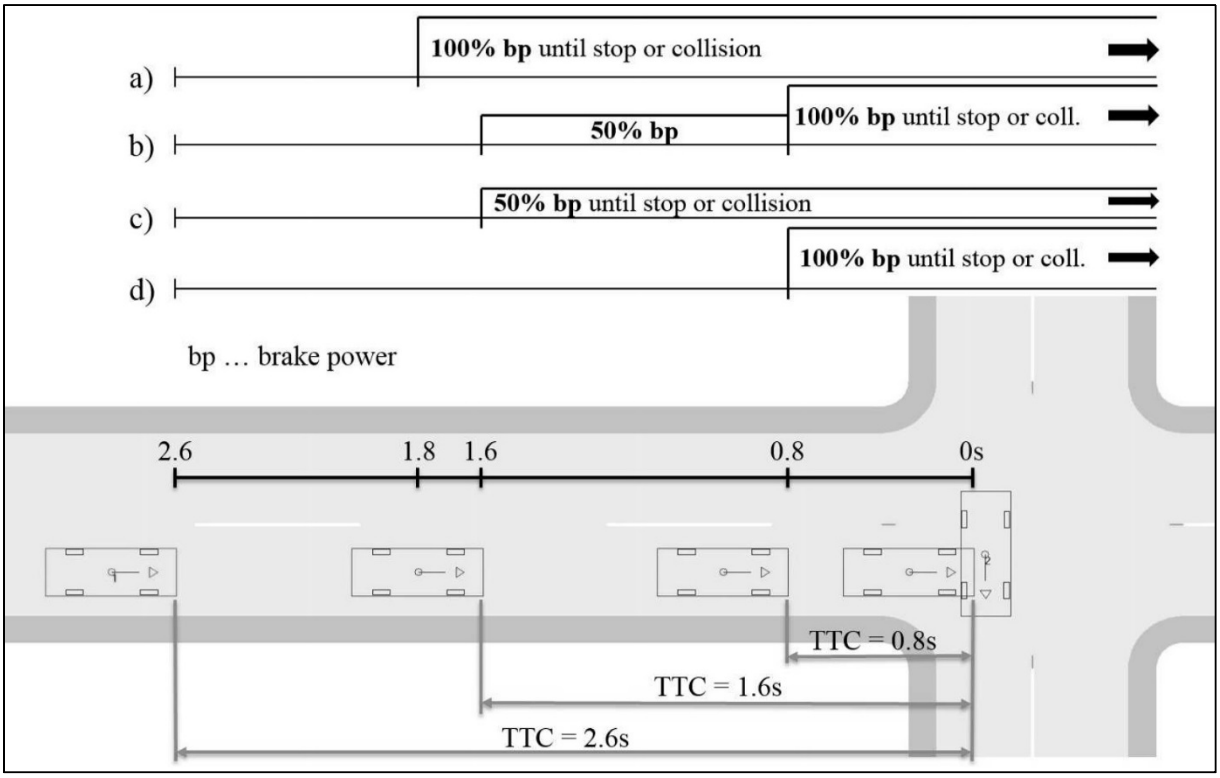

Figure 4. Examined intervention strategies for ICAS

Assessment Function

Basically the evaluation of the system effectiveness is based on a pre- post comparison between the baseline and the system simulation. If the ICAS included in the system simulation didn't contribute to avoid the collision between both vehicles, a potential of the examined system is calculated. The potential builds up on three parameters (delta-v, EES and MAIS3+). For each parameter the difference between baseline and system simulation is calculated. This comparison of delta-v, EES and MAIS3+ between baseline and system simulation indicates a positive or negative influence of ICAS on the circumstance of the accident.

LIMITATIONS

Currently ZEDATU only provides real accidents with at least one fatal injured road user. More precisely at least one road user either died because of the direct consequences of the accident or because of non-accident causal conditions (e.g. advanced age, heart attack, etc.). Therefore this study builds up on fatal road traffic accidents, while slight or severe road traffic accidents haven't been considered yet.

Moreover only traffic accidents at junctions between two cars, vans, small busses or lorries were taken from ZEDATU for evaluations concerning this study.

The risk curves for the assignment of injury severity (see Figure 2) origin from a finite amount of real accidents in different impact scenarios. Therefore slight variances between the actual AIS classification according to the real accident data and the generic probability of a MAI3+ injury severity are possible. Moreover it is mentioned that accident impacts have only been evaluated for the vehicle drivers.

View restrictions have been considered within the system simulations as far as possible. The transparency for radar waves of special objects (e.g. hedges, etc.) hasn't been included yet into the geometrical detection algorithm.

RESULTS

The following results build up on 44 reconstructed real junction accidents. At most each accident could include eight system simulations with results for both vehicles (theoretically 352 system simulation and 704 individual results at most). Depending on the individual calculated TTC for each real accident, ICAS strategies a), b), c) and d) have been integrated in separate system simulations. If TTC was calculated to a value of 1.7s, strategies b), c) and d) could be investigated in separate simulations exemplarily. Therefore ICAS a) couldn't be evaluated in this example, because ICAS a) requires a TTC of at least 2.6s or higher.

Figure 5 illustrates the absolute and cumulative frequency of TTC. Only accident cases with exact opponent detection were considered in this diagram. Theoretically each accident case results in two TTC values (system integration and evaluation for both vehicles separately). Therefore 88 results for TTC at most would be possible. Nevertheless in 10.2% of all reviewed cases the ICAS couldn't detect the opponent properly. The consideration of the absolute frequency reveals that about 50% of all examined cases took place within a TTC time frame of approximately 0.8 to 1.2s. In 92% of all examined junction accidents the TTC time frame was smaller than 1.8s according to the cumulative frequency. This result clarifies the comparatively small potential of Intersection Assistance Systems whose intervention strategies need TTC time frames bigger than 2s. The biggest TTC of all considered system simulations was calculated to 2.9s at a left turning scenario.

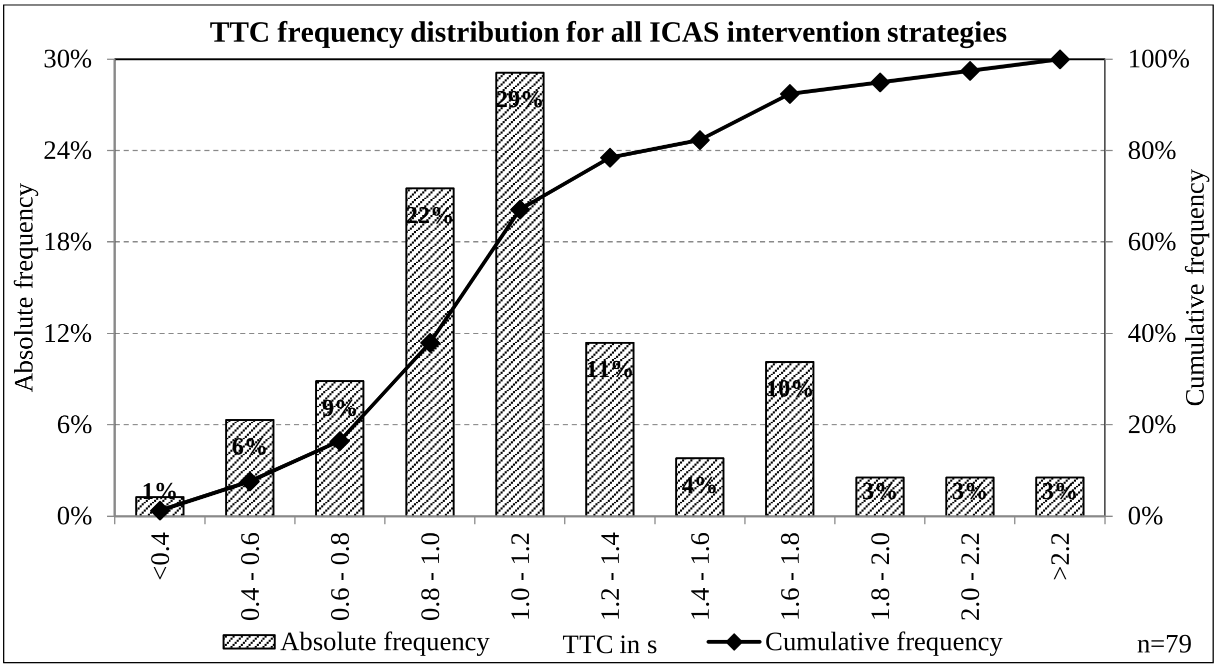

Figure 5. TTC frequency distribution for all ICAS intervention strategies

A comparison between the frequency distribution of baseline and system simulations for the Principal Direction of Force (PDoF) is shown in Figure 6 left. The PDoF classifies the direction of the impact force for the reviewed vehicle. The direction is defined according the clock face.

The evaluation of the system simulations revealed significant changes in PDoF. Through the integration of ICAS the impact force direction at 12 o'clock increased from 20% to 25% (see Figure 6). Furthermore the evaluation illustrates a distribution of the PDoF between 10 and 1 o'clock for approximately 80% of all examined junction accidents. Generally it was observed that the PDoF is moving towards more frontal impact forces i.e. PDoF of 12 o'clock. This change positively effects the probability of a MAIS3+ injury severity for the vehicle driver. The bigger crush zone of the vehicle front can absorb more deformation energy compared to the vehicle side and reduces therefore the probability of MAIS3+ injuries. The correlation between PDoF and the mean average delta-v for baseline and system simulations (see Figure 6 right) reveals a significant reduction of the mean average delta-v between 8 and 10 o'clock as well as between 1 and 4 o'clock. The highest reduction of mean average delta-v (23.2km/h) has been evaluated at 3 o'clock. In this study only junction accidents with frontal and side collisions have been considered. Therefore no correlation between baseline and system simulations concerning PDoF at 6 o'clock exists.

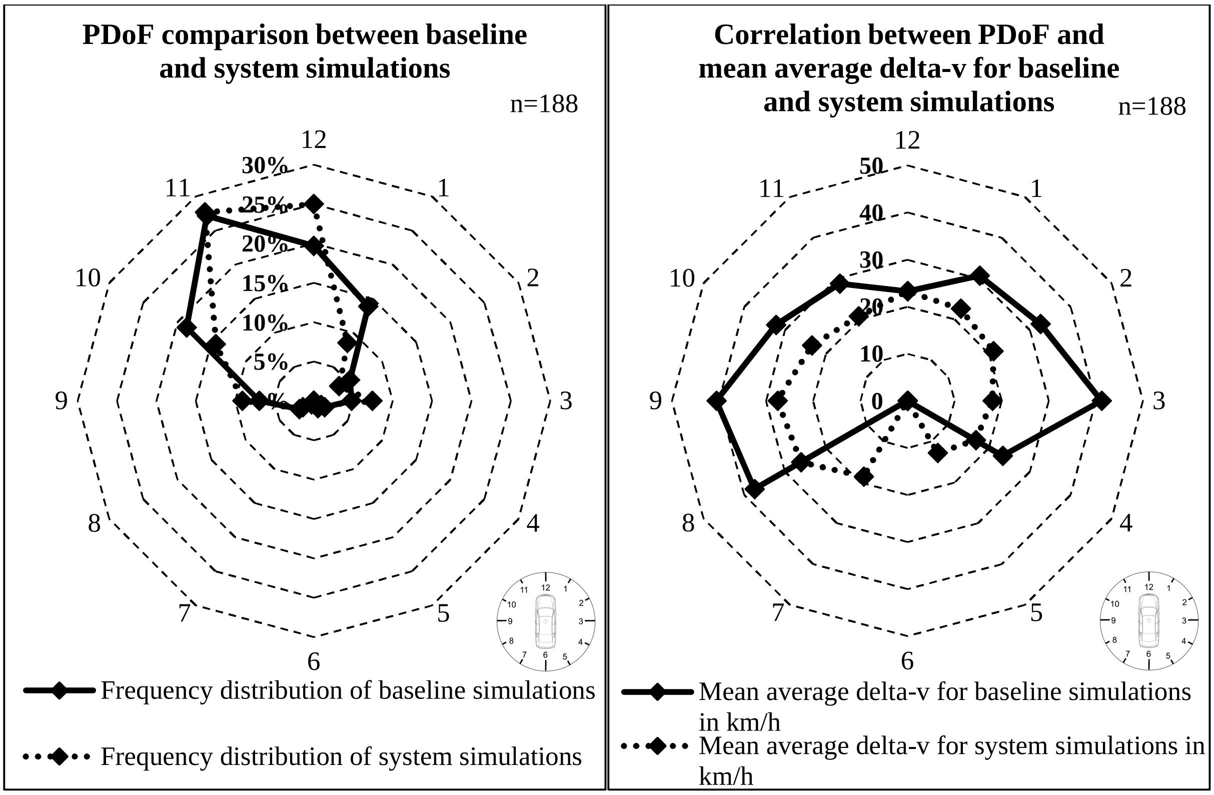

Figure 6. PDoF comparison between baseline and system simulations is shown in the left diagram. The correlation between PDoF and mean average delta-v for baseline and system simulations is illustrated in the right diagram.

The most important examined sensor system for the detection of other road users or objects is the SRR. In 43% of all investigated system simulations equipped with ICAS b) or c) the detection happened by using the SRR. In 29% of those system simulations the detection was performed by using LRR in combination with SRR. Considering ICAS d) the percentage of the SRR detection even rises up to 86% and 9% combination between LRR and SRR.

The evaluation of ICAS a) within the system simulations (Figure 7 left) revealed a mean reduction of the probability of a MAIS3+ injury severity of approximately 66% (MD=67.00%, SD=38.43%). Due to the high required value of TTC (>2.6s) the intervention strategy ICAS a) could only be integrated in 5% of all investigated junction accidents. However, each system simulation with TTC>2.6s has been avoided by integrating ICAS a). In 95% of all cases the opponent detection either happened at TTC<2.6s or no opponent detection happened (opponent didn't enter the sensor view cone or opponent left the view cone before system initiation). The intervention strategy ICAS b) reached a mean average reduction of the MAIS3+ injury severity of approximately 44% (MD=44.00%, SD=33.04%) and ICAS c) of 42% (MD=50.00%, SD=30.86%) according to Figure 7 left. System simulation with ICAS b) as well as ICAS c) allowed to avoid collision of approximately 10% of all examined cases. In 14% of the reviewed cases the collision could not be avoided by using ICAS b) or ICAS c), but the values for MAIS3+ were reduced significantly. The lowest mean average reduction for MAIS3+ was calculated for the intervention strategy ICAS d) with 30% (MD=19.50%, SD=31.06%). Nevertheless the highest potential considering injury mitigation was calculated for ICAS d) with 77% of all investigated cases. In only 11% ICAS d) did not contribute to reduce passenger's loads. Additionally it is mentioned that in some cases the values for MAIS3+ did increase although ICAS d) was integrated. Therefore the minimum value for ICAS d) (lower whisker) in Figure 7 left is negative.

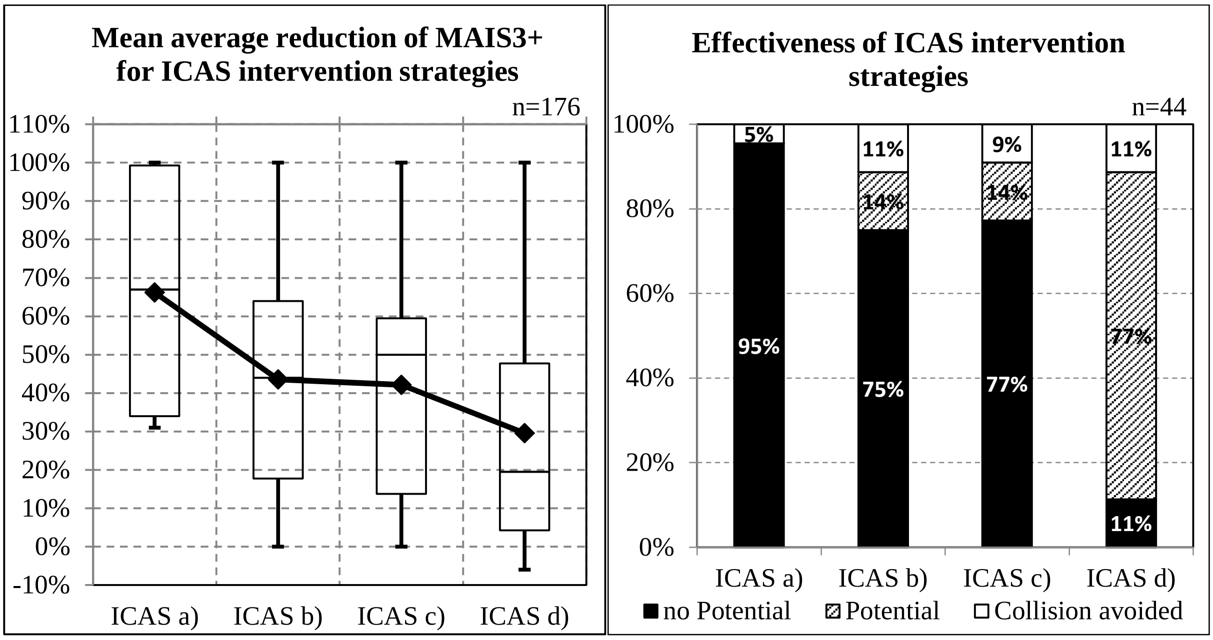

Figure 7. Mean average reduction of MAIS3+ and effectiveness for all investigated ICAS intervention strategies - The ranking of the effectiveness of ICAS intervention strategies in the left diagram refers to the height of the mean average reduction of MAIS3+ injury severity. The right diagram illustrates the effectiveness of ICAS intervention strategies concerning all reviewed junction accidents.

CONCLUSION & DISCUSSION

Intervention strategies that require a TTC>1.8s don't have a huge impact on the prevention of junction accidents or the mitigation of injury severity. About 90% of the evaluated cases had a TTC lower than 1.8s, because the opponent couldn't be detected earlier through the on-board sensor systems. To mention the short time frame before the collision, semi- as well as fully autonomous intervention strategies seem to be more appropriate than simple warning algorithms for intersection assistance.

In approximately 22% of all reviewed system simulations the probability of a MAIS3+ injury severity increased within the system simulations compared to the baseline simulations. In these simulations the opponent had more time to enter the danger zone, because of the system braking manoeuvres. Therefore collisions with more overlap and increased values for delta-v happened.

OUTLOOK

For further analysis of accident occurrence at junctions more detailed accident data is necessary. ZEDATU database was used to provide real accident data for accident simulations. Only accidents with at least one fatal injured vehicle passenger were considered for this study. Future evaluations should also consider real accidents at junctions with severely and slightly injured vehicle passengers. The effects of ICAS on road safety should also be investigated on trucks, coaches, motorcycles and pedestrians.

An interesting approach to increase road safety is C2C (Car-to-Car) and C2I (Car-to-Infrastructure). These systems could contribute to increase the functional range (on-board sensing systems) of existing ICAS to allow warnings on time or to enhance current intervention strategies. Today many unresolved issues (technical, standardisation, development, etc.) remain considering C2C and C2I. Nevertheless they will contribute to vehicle safety in future. [17, 2005] Therefore the assessment of potential in advance could support the further development of these systems. Further approaches for the assessment of the effectiveness of Intersection Assistance Systems could exemplarily consider traffic sign or traffic lights recognition and the consideration of transparent objects for radar waves (e.g. hedges, etc.).

ACKNOWLEDGMENT

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Crash Simulation for Biomechanical Research

H Johannsen*, M Stein**, D Otte*

* Unfallforschung Hannover, Karl-Wichert-Allee 3, 30625 Hannover, DE
** TU Berlin Kraftfahrzeuge, TIB 13, Gustav-Meyer-Allee 25, 13355 Berlin, DE

Abstract

Since a number of human models have been developed it appears sensible to use these models also in the accident analysis. Especially the understanding of injury mechanisms and probably even injury risk curves can be significantly improved when interesting accidents are reconstructed using human body models. However, an important limitation for utilising human models for accident reconstruction is the effort needed to develop detailed FE models of the accident partners or to prepare the human model reconstruction by running physical accident reconstructions.
The proposed approach for using human models for accident reconstruction is to use simplified and parametric car models. These models can be adapted to the crash opponents in a fast and cost effective way. Although, accuracy is less compared to detailed FE models, the relevant change in velocity can be simulated well, indicating that the computation of a detailed crash pulse is not needed.
Two frontal impact test accidents that were reconstructed experimentally and using the parametric car models are indicating sufficient correlation of the adapted parametric car models with the full scale crash reconstructions. However, further developments of the parametric models to be capable for the use in lateral impacts and rear impacts are needed. For the PC Crash simulation runs the output sampling rate is too large to allow sufficient analysis. In addition the performance appears to be too general.

INTRODUCTION

Accident research allows to statistically analyse a set of accidents for example to review accident causation, injury pattern and effectiveness of safety devices. However, for more detailed investigation often single case studies are used to better understand injury causation, injury criteria etc.
Adolph et al. [1] for example studied lower spine injuries and concluded that frontal accidents not involving the standard crash structures and frontal accidents involving an important lateral component are prone for low severity accidents with lower spine injuries. However, they were unable to explain how these accident mechanisms cause these injuries.
In a sequence of child safety projects single accident cases were experimentally reconstructed to pair the injury severity with the dummy readings [2]. This approach allows more insight into the accident but the physical testing approach allows only to test with dummies that are not a perfect surrogate for humans. Human body models would probably offer a better opportunity but a full numerical accident reconstruction involving complete FE models of the involved opponents are too costly. Another issue is the lack of availability of the FEM vehicle models due to confidentiality and the usage of different types of crash solvers at different OEMs.
Technische Universität Berlin developed simplified Parametric Car Models for the analysis of car crash compatibility issues [3]. These models in principle would offer to adapt the vehicle models to the cars that were involved in the crash in an easy and cost effective way and to run an FE reconstruction of the accident in order to acquire the pulse and vehicle movement during the crash and to transfer this knowledge to interior models. This approach would help to gain additional knowledge from single accident cases at a relative low cost level.
In this study the approach is tested using accident cases that were already experimentally reconstructed in order to compare the simulation results with the testing results. In addition to the FE models the PC-Crash models will be used to compare an even less complicated approach. Here only the pulses are evaluated; in a next step dummy readings need to be gathered.

DESCRIPTION OF THE METHODOLOGY

A general overview of the proposed methodology is shown in Figure 1.

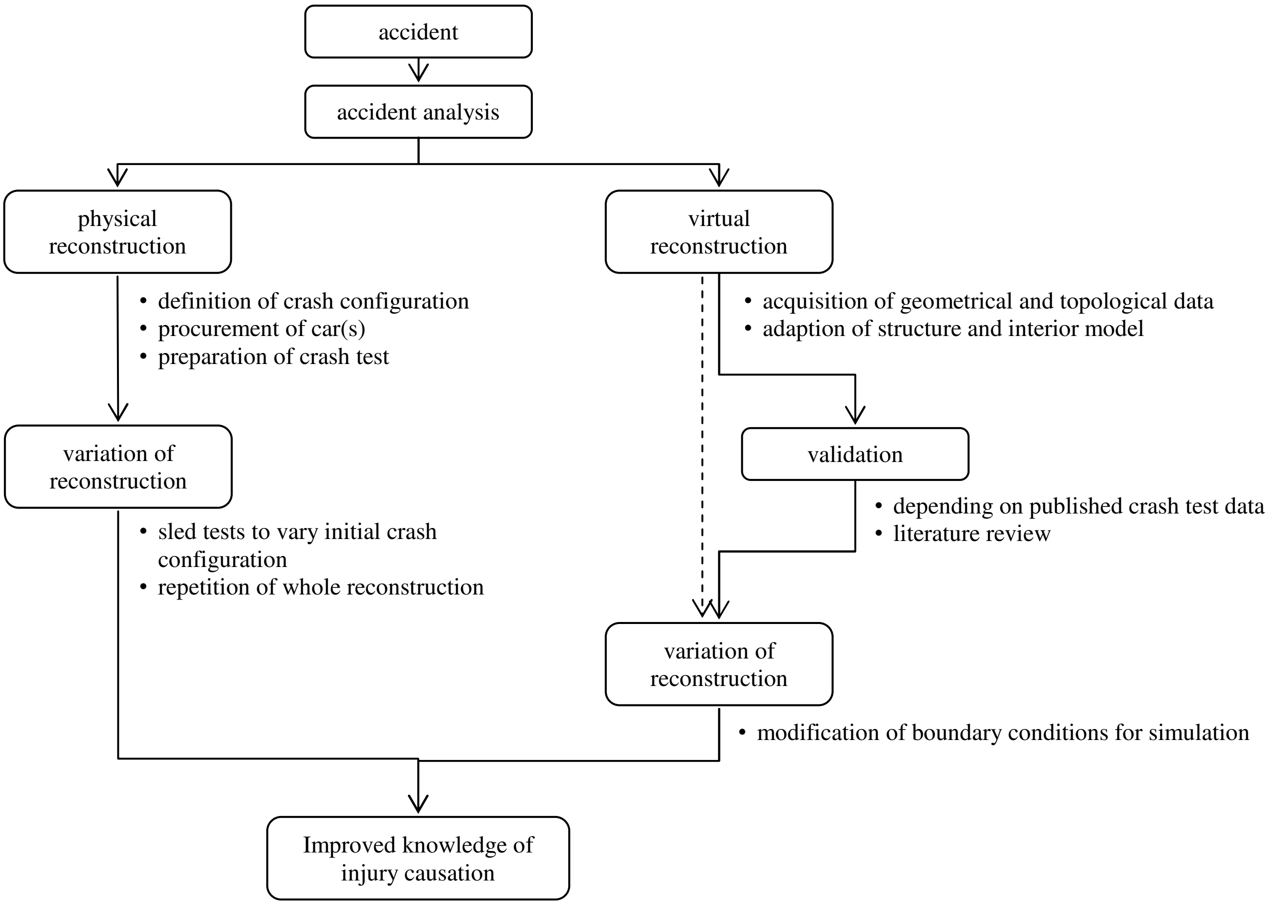


Figure 1: Comparison of physical and virtual reconstruction

Today accident reconstruction for biomechanical research often is done by physical crashes. This offers the advantage to replicate the real accident in detail, but requires a detailed accident analysis to minimise the number of unknown variables. To limit the costs only one full-scale crash can be conducted. Depending on the correlation of real accident and reconstruction sled tests are used to vary parameters of the crash condition. But here only minor changes can be realised because initial velocity and crash pulse as well as impact location and impact angle are fixed due to the conducted full-scale crash. However, variation of seat and seating position or different kinds of misuses with regards to the usage of CRS are possible. The most important limitation is that only ATDs can be used in physical reconstruction to investigate injury mechanisms. Thereby requirements like robust design, repeatability and reproducibility restrict the significance of the measurements and the correlation to real human beings.

The availability of human body models (HBMs) offers the possibility to use virtual surrogates for accident reconstruction providing detailed information about injury causation. However, the usage of those HBMs only makes sense if there is an appropriate virtual environment to simulate the accident. In order to ensure an appropriate virtual environment it would be best to use detailed FEM models of the accident partners. This would guarantee validated models and therefore the best correlation to the crash performance. But typically the OEM FEM models are validated only for the specific load cases as required in compulsory and consumer crash tests. Furthermore the FEM models are not available due to confidentiality reasons and they are modelled in different crash codes depending on the manufacturer; making it difficult to use them in one common simulation. Alternatively generic models are available representing typical characteristics of crash performance of a vehicle or an occupant protection system [3]. But due to the generic design their validity is limited to general evidence. Their usage for specific analysis as needed for accident reconstruction is not sensible.

The development of parametric models closes this gap. As explained in detail in the following section the parametric design allows the adaption of a baseline model to represent the specific characteristics of the accident partners in terms of mechanical behaviour of the crash structures. Thereby the validity of the numerical models can be confirmed with publicly available crash test data. Amongst the usage of HBMs one further advantage is the limited effort needed to vary the boundary conditions for the simulations. Thus a better adaption of the crash configuration to the real accident is possible which lead to a better understanding of injury causation.

Parametric Car Models – PCMs

The basic idea of the PCMs was to develop a tool to investigate structural interaction in frontal car-to-car crashes. Thereby the FEM models should have the capability to represent typical structural concepts of the crash relevant structures that can be found in different vehicle classes. To fulfil this requirement a full implicit parametric CAD model of a vehicle was developed [3]. This offered the possibility to modify geometry and topology of the crash relevant structures in a time efficient manner. In addition the specific CAD software can automatically create a computable FEM model without further pre-processing. To allow a larger degree of freedom for the geometrical and topological modifications (e.g. changing the distance between the longitudinal members or changing the height of the sub frame) all front end structures were modelled in a simplified manner, see Figure 2. That means all components of the power train were combined into one rigid structure and the wheel suspension was simplified to represent the wheel kinematics. However, the primary energy absorbing structures and the secondary energy absorbing structures as well, were modelled to represent their typical mechanical behaviour during the crash like folding, bending and Euler buckling.

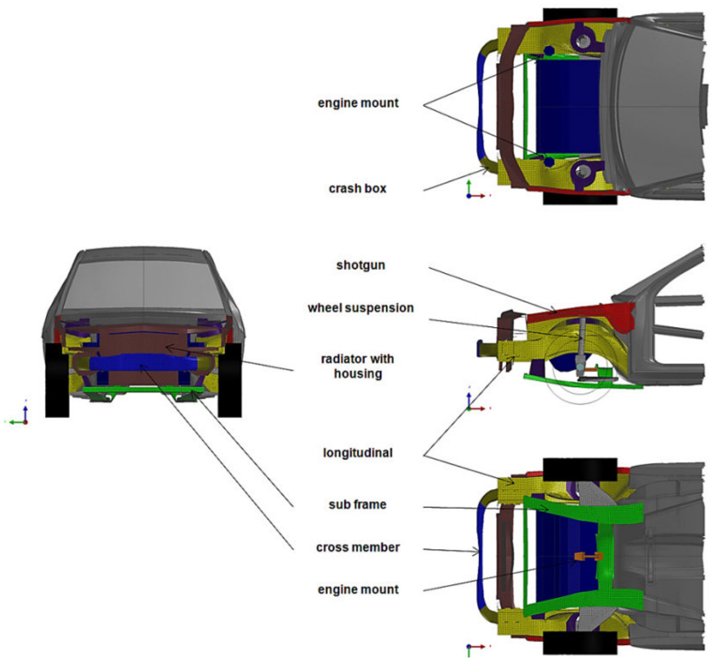


Figure 2: Front end structures of the PCMs [3]

Because the combination of the power train components into one common part lead to untypical deformation pattern in the PDB test procedure [4] the approach of the PCMs was reviewed and a second generation was modelled, based on the same modelling approach. The main improvements are the generic design of the front end structures derived from a geometrical database [5], more realistic design of power train components (e.g. separated engine and gear box, longitudinal or lateral engines, cooler and cooler housing) and wheel suspension. Furthermore a fourth vehicle class representing off-road vehicles was added to the existing super mini, family and executive car classes see Figure 3.

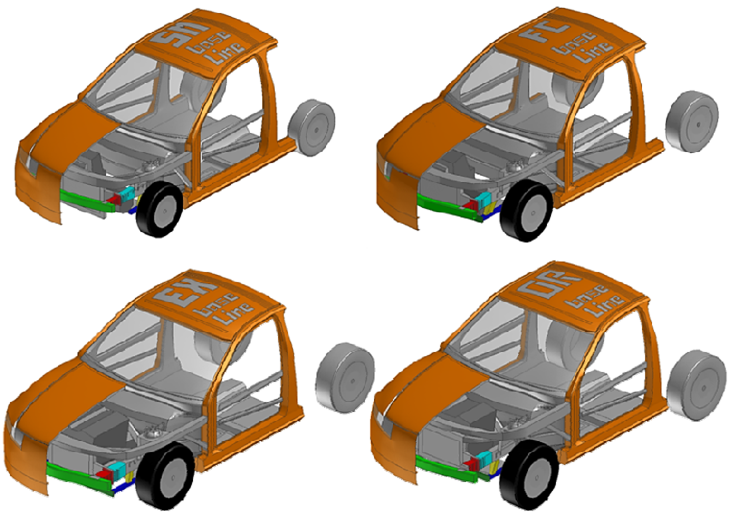


Figure 3: Vehicle fleet of 2nd generation of PCMs (top left: Supermini; top right: Family car; bottom left: Executive; bottom right: Off-roader)

To ensure model quality and transferability of the results efforts were spent to verify the modelling approach and to validate the crash performance of the improved PCMs. Crash test data of FWRB 56 (Full Width Rigid Barrier, 56 km/h closing speed, as used e.g., for US NCAP) and ODB 64 (Offset Deformable Barrier, 40% overlap, 64 km/h closing speed, as used e.g., for IIHS) crashes, in combination with low speed crashes (repair crashes defined by RCAR) were used to derive a generic crash performance for each vehicle class. Exemplarily the crash performance of the Super Mini model (SM) in comparison to reference cars is shown in Figure 4.

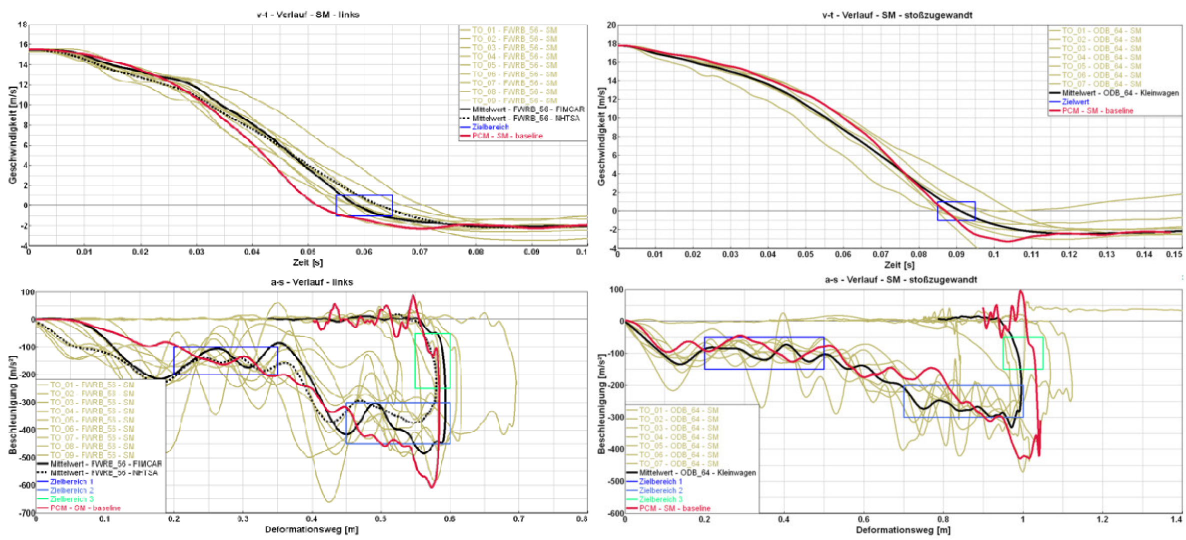


Figure 4: Crash performance of Super Mini model (left – FWRB 56; right – ODB 64)

The generic design and crash performance of the 2nd generation PCMs with regards to the corresponding vehicle class is a good starting point to adapt the models to specific cars. Because the crash performance mainly is controlled by the crash relevant structures the implicit parametric CAD models allows fast and robust modification of the baseline structures. Once the geometry and topology of the case car is modelled only slight adjustments of the stiffness of the structures will be necessary.

To adjust the crash performance public available crash test data can be used as well as published data of used materials.

DESCRIPTION OF THE SAMPLE ACCIDENTS

The following selection criteria were used for the definition of the cases to be checked from the experimentally reconstructed accidents from the CHILD and the CASPER project:

- frontal impact (the PCMs were developed for frontal impact)
- impact against rigid object (in order to reduce the modelling effort and variability for the initial investigations by using one car only)

Furthermore it was important that accident data as well as reconstruction data was made available by the owner of the data for this study. Finally after selecting the first accident it appeared sensible to use as the second accident one with a similar case car. This approach allows to check the robustness of the model for different impact situations which was ranked higher than to show for two different cars that the models can be created.

Accident 1

The driver of a VW Polo 6N (model introduction 1994) went out her line, in the following the car touched a tunnel wall and impacted with the right side (off-centred by approx. 250 – 300 mm) a pole including a concrete block below the pole (actually the base of the pole). The impact speed was estimated to be between 50 and 55 km/h.

The female driver of the car sustained MAIS 2 injuries (injuries at head, chest and abdomen). The 3 years old boy sitting behind the driver using a backless booster sustained AIS 3 chest injuries, AIS 5 abdomen injuries and AIS 5 spinal injuries.

For the experimental reconstruction the set-up was simplified using a rigid off-set barrier with a rounded edge representing the combination of pole and concrete base of the pole.

The deformation pattern of the accident car and the reconstruction car is shown in Figure 5. In the accident car the right shotgun is less deformed than the rest of the right car front, which is not the case in the reconstruction. However, the reconstruction was considered to be valid considering that the majority of energy was expected to be absorbed by the longitudinals and the engine block.

accident car reconstruction car

Figure 5: Comparison of vehicle damage between accident and accident reconstruction Accident 1

For the numerical reconstruction using PC Crash both configurations, the one corresponding to the accident and the one corresponding to the experimental reconstruction are analysed. For the FE model only the configuration according to the reconstruction is considered. The crash pulses are shown below in the Results section and the Discussion section together with the simulation results.

It is important to mention that it appeared to be difficult to reproduce the occupant kinematics causing the observed injuries with the Q3 dummy. In the end three sled tests using an approximation of the crash pulse were conducted with different initial dummy postures. Finally a posture with the feet at the seat cushion and a sloughed posture was judged to reproduce the expected occupant kinematics best. However, it can be expected that using a human model would allow much better insight.

Accident 2

As mentioned before the main reason for selecting this accident was to use the same vehicle model to check model robustness. Although both accidents were pole impacts the first experimental reconstruction was conducted against an off-set rigid barrier. The experimental reconstruction of Accident 2 represented an almost centred impact against a pole. In addition to the differences in the impact opponent the impact speed was different too.

The driver of a VW Polo 6N (model introduction 1994) left the road to her left side and collided purely frontally with an off-set of approx. 60 mm to the centre line against a pole with a diameter of 330 mm. The impact speed was calculated to approx. 35 km/h.

The female driver sustained MAIS 1 injuries while the 7 years old boy using the front passenger seat suffered from an AIS 2 abdominal injuries, an AIS 1 neck distorsion and an AIS 1 thorax contusion. The child was using a backless booster. The front passenger seat airbag deployed during the accident (however, the reconstruction video did not show important interaction between dummy and airbag, except some minor contacts between extremities and airbag).

The deformation pattern between accident and experimental reconstruction are similar, see Figure 6. As for Accident 1 crash pulses are shown below together with the simulation results.

accident car reconstruction car

Figure 6: Comparison of vehicle damage between accident and accident reconstruction Accident 2

PREPARATION OF THE ADAPTED PARAMETRIC MODEL

The following section describes the adaption of the parametric structure model to the VW Polo 6N (model introduction 1994) which is further referred to as case car. In the first part the geometrical adaption of the 2nd generation PCMs (Supermini), further referred to as baseline PCM, is explained briefly. Here, the fitting of the generic structures of the baseline PCM to the case car is described. In the second part the validation of the model is described.

Geometrical adaptation

The geometrical database [5] used to create geometry and topology of the PCMs provides information of approx. 50 pre-defined measurement points for the front structures. Most of the measurement points describe the distance to fix references like the ground or centre of the front axle. However, several points are in relation to other structures and create variable measurement chains which can differ depending on absence or presence of components like the compressor of the air conditioner or different packages influencing the position of e.g. radiator or alternator.

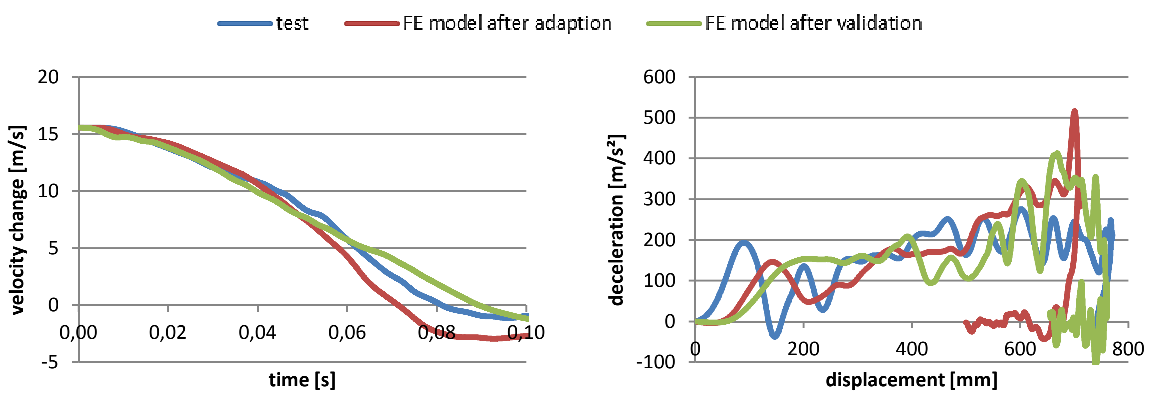
To adapt the baseline PCM to the case car the measurement points according to the geometrical database were measured and transferred to the implicit parametric CAD model. In addition to the pre-defined points new components were added to the engine compartment: starter battery and air filter. Because the position and the mounting of these components differ depending on the package, they are not included in the baseline PCMs. The data acquisition was done without disassembling the front end structures of the case car, except the front bumper. Thus, only little effort was needed to collect all relevant data. For trained staff it can be expected that one person day would be sufficient to acquire the data. General material data was acquired from literature [6].

Validation test

A large number of cars is already crash tested and the results are published in more or less detail. In order to validate the adapted model public available crash test results of the accident car were reviewed. For the case car of this study the following crash test results were published:

- Euro NCAP (40% overlap off-set deformable barrier, 64 km/h)
- auto motor und sport (50% overlap off-set rigid barrier with 30°, 55 km/h)
- FWDB test at NHTSA crash test data base (full-width deformable element, 56 km/h)

The Euro NCAP raw data appeared to not be available for this study. The auto motor and sport test was judged to be too similar with the experimental reconstruction of Accident 1 to proof the concept. Basically it is an advantage to correlate the response of the FEM model with the real car in a test that is close to the accident to be considered. However, the idea of the proposed methodology is to use only geometrical data of the crash relevant structures to adapt the generic FEM models to the specific car. Depending on the availability of crash test data the crash performance of the FEM model can be validated within this intermediate step. But due to the diverse number of real crash configurations these crash test data normally do not represent the real accident. Therefore the validation of the adapted FEM model is just a possibility to ensure the model quality but is not needed in principle. Following that the FWDB test was used to optimise the model.



velocity change characteristics

deceleration-displacement plots

Figure 7: Crash performance of adapted and validated PCM

Figure 7 exemplarily shows the crash performance of the PCM after only geometrical and topological adaption and after the validation process. The PCM after adaption (red line) showed relative stiff deformation behaviour, resulting in an early time to zero for the velocity at approx. 70 ms and a too short deformation length, approx. 700 mm. By stepwise decreasing the wall thickness of the rear parts of the longitudinal members and the shotgun the deceleration peak at the end of the crash could be decreased. Thus a good correlation to the maximum deformation could be achieved. The lower deceleration level had a positive influence on the velocity, in particular after 50 ms of the crash. In total the validation process took two person days which is comparable to the time needed to prepare a crash test.

COMPARISON OF ACCIDENT RECONSTRUCTION APPROACHES

Accident 1

For Accident 1 the pulse of the FE simulation approximates the pulse of the test quite well during the first 50 ms, see Figure 8. The PC Crash simulations show a low time resolution and following that serrated curves. The output time step was set to the minimum that is allowed by PC-Crash. However, the large distance between the data points creates uncertainties as the frequency of the measurement signal is much smaller than the sampling rate. The differences between the pole configuration and the configuration with the off-set rigid impactor are small in the PC Crash simulations. As mentioned before in the FE simulation only the chosen approach for the experimental accident reconstruction was simulated.

It needs to be acknowledged that the stiffnesses in the PC Crash simulation of the collision partners were considerably increased compared to the standard stiffness in order to avoid that the car passes through the object.

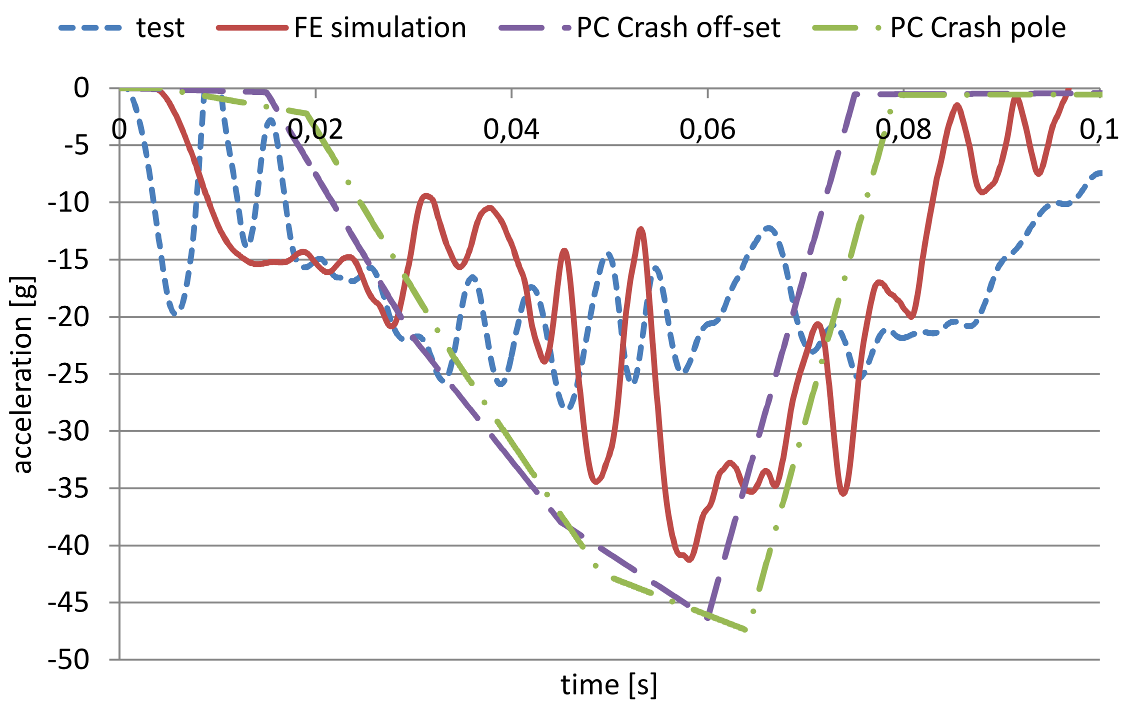


Figure 8: Pulse comparison Accident 1

Accident 2

The pulse comparison between experimental accident reconstruction and the numerical simulation approaches in Accident 2 appears to be much better than for Accident 1. Similarly to Accident 1 the PC Crash plot shows a low sampling rate. The FE model approximates the test result sufficiently for the whole duration of the impact, see Figure 9.

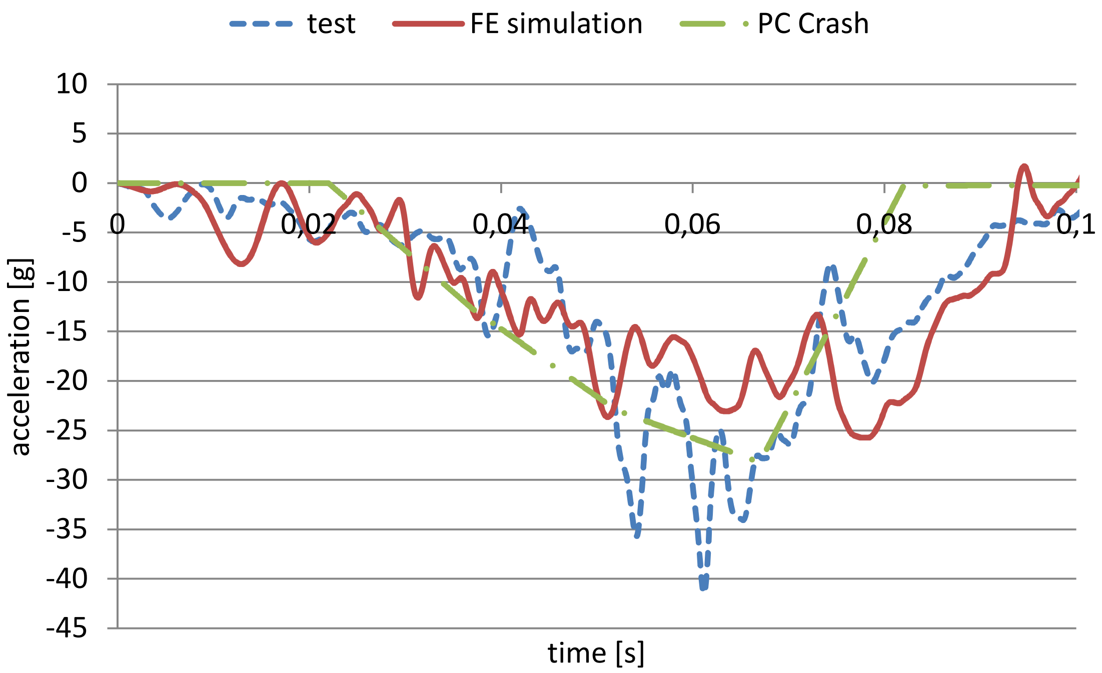


Figure 9: Pulse comparison Accident 2

DISCUSSION

Pulse Criteria

Before starting to discuss the simulation results it is important to start with a general discussion on pulse criteria. Pulse criteria are normally used to judge the quality of sled tests w.r.t. the car test they should represent. There are mandatory pulse requirements, e.g., as defined by UNECE Regulation 94 for sled tests and by Euro NCAP for the knee mapping protocol [7]. Furthermore there are internal pulse requirements defined by car manufacturers for their suppliers or defined by the owner of the sled facility. Finally there are fixed corridors defined for acceleration curves to be met, e.g., for sled tests according to UNECE Regulation 16 and 44.

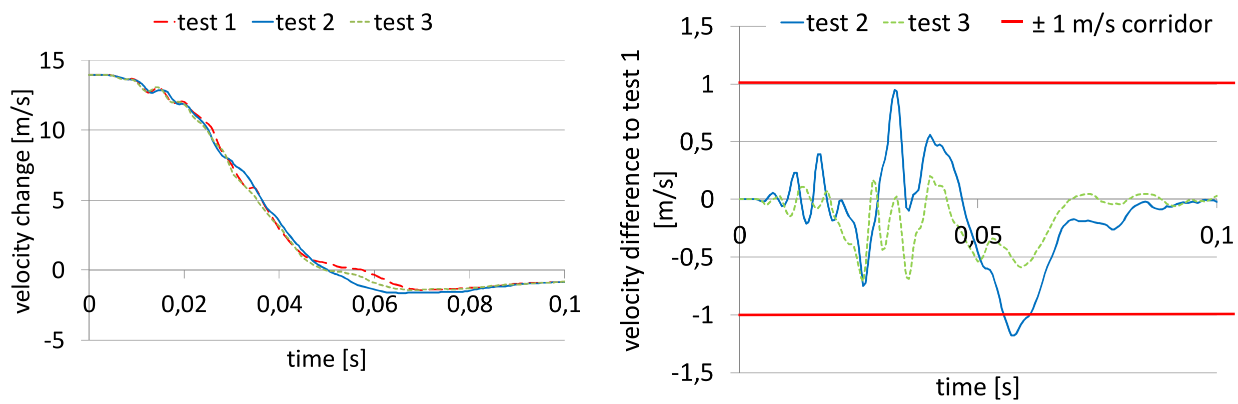
There is a general trend not to assess the acceleration itself but the velocity change curves. This account for the fact that the acceleration signal is often spiky and difficult to match while it is assumed that individual spikes do not influence the occupant loading in a significant way. In order to account for the spikes an acceleration corridor is often quite wide (e.g., UNECE Regulation 44 corridor). When computing the velocity change curve form the acceleration curve the signal is somehow filtered resulting in a smoother curve. This allows a narrower corridor.

For UNECE Regulation 94 a tolerance of +/- 1 m/s is allowed. The same requirement is often used in internal specifications according to interviews with OEM and users of sled test facilities. However, there are also more stringent requirements. For example the delta-v corridor for the new side impact test procedure for CRS according to UNECE Regulation 129 defines a maximum tolerance between lower band and upper band of approx. 1.2 m/s. Similarly Euro NCAP requires a tolerance of +/- 0.6 m/s while after 50 ms the sled may be faster than that [7].

Following the pulse criteria described above it appears sensible to follow the velocity change approach.

In order to fix a reasonable threshold a number of repeated car tests are analysed below. The selected tests are always tests against rigid objects in order to rate only the repeatability of the car and not the repeatability of a deformable element. In most of the cases old and used cars were utilised.

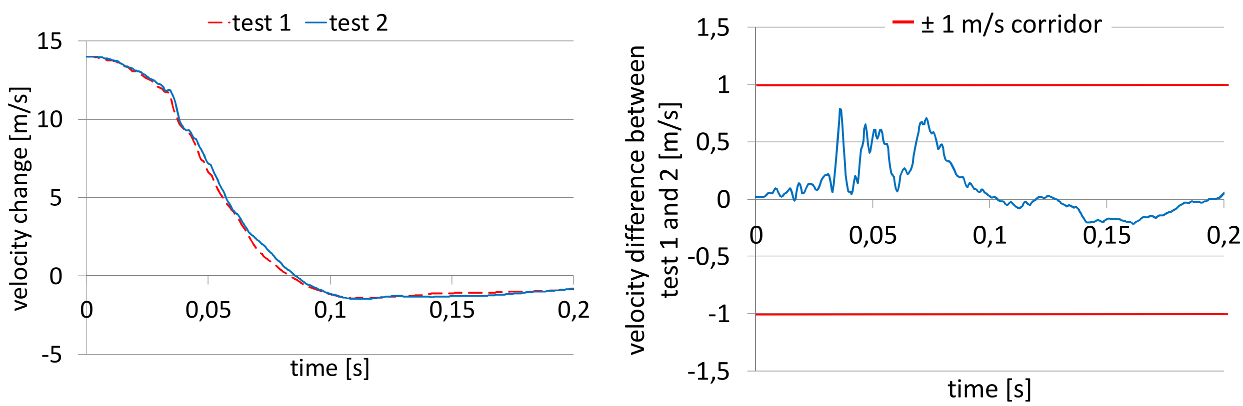
In test series A three full width rigid barrier tests using a city car that was sold between 1996 and 2008 are analysed. All tests were conducted using used cars with introduction year in 1996. Test 3 exceeds the 0.6 m/s tolerance band as defined by Euro NCAP, see Figure 10. Test 2 touches the 1 m/s limit before 50 ms and exceeds it after 50 ms.



velocity change characteristics of test 1, 2 and 3 velocity deviation between test 1 compared to tests 2 and 3

Figure 10: Velocity change comparison in test series A

In test series B and C a Super Mini with first introduction of the used facelift model in 1997 was crashed against a rigid off-set barrier with a horizontal off-set of 40% and a ground clearance of the barrier forcing an underride behaviour of the car. The situation was meant to represent an actual frontal collision accident of the respective car against the rear end of a truck. The tests were conducted 4 times but using two different impact velocities in each case for two tests. Furthermore for each speed different dummies were used (5th percentile or 50th percentile). Following that the complete test series was split into test series B and C to better account for the different impact speed and the different test weight; it is important to note, that the different test mass resulted in a slightly different ride height causing different underride behaviour. In test series B the velocity change deviation between the two tests exceeds 0.6 m/s but stays within the 1 m/s criterion, see Figure 11.



velocity change characteristics of test 1 and2 velocity deviation between test 1 and 2

Figure 11: Velocity change comparison in test series B

In test series C the deviation in velocity change never exceeds the 0.6 m/s criterion, see Figure 12.

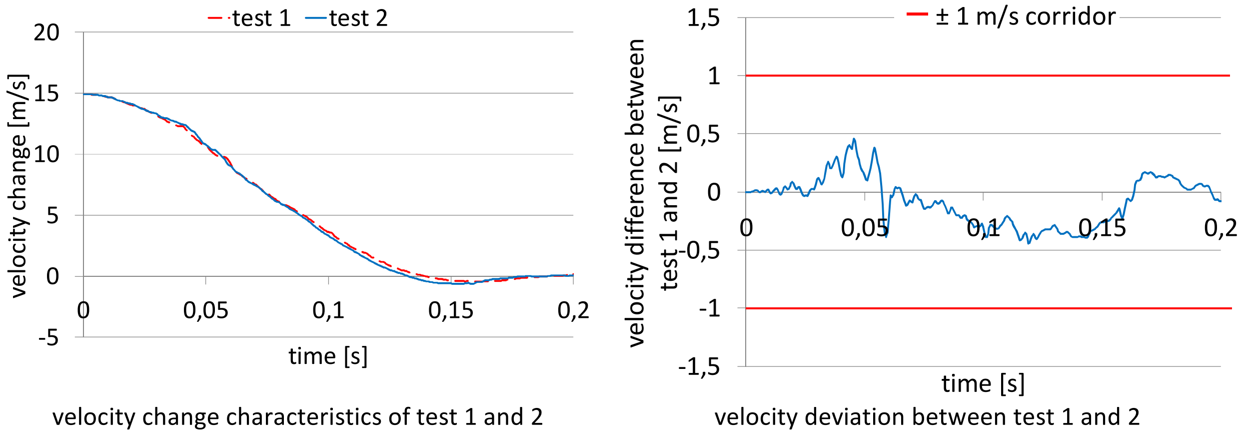


Figure 12: Velocity change comparison in test series C

While test series A, B and C were conducted at TU Berlin test series D is acquired from the NHTSA crash test data base [8]. The rational behind looking for another test series is to check another test lab on the one hand and to include a newer car in the study on the other hand. By random choice a large family car (Model Year 2011) that was tested twice according to the US NCAP full frontal test protocol was selected.

In the two tests the velocity difference exceeded the 1 m/s criterion for a short peak and the 0.6 m/s criterion several times, see Figure 13.

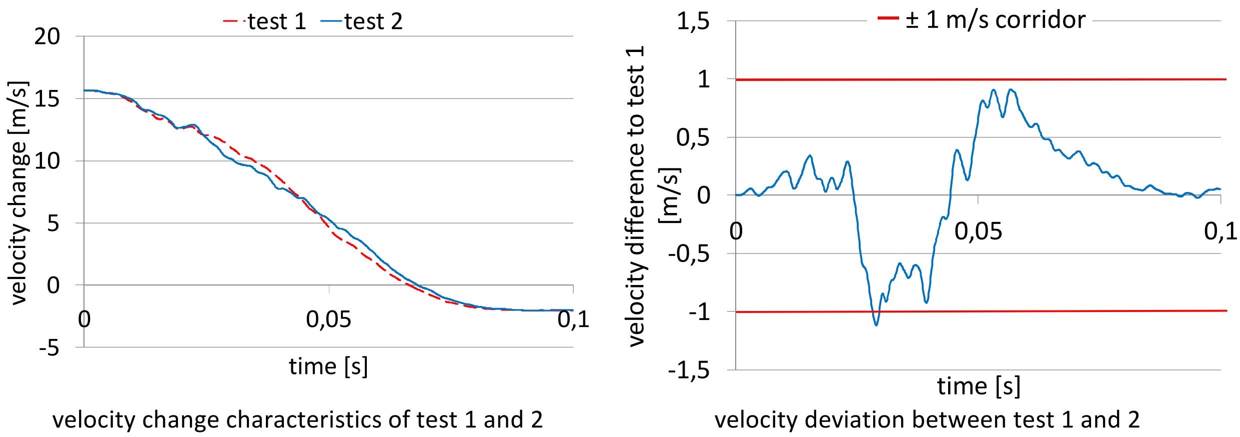


Figure 13: Velocity change comparison in test series D

To conclude the section on pulse criteria it appears to rate the quality of correlation between test and simulation for the accident reconstruction approach by the difference in velocity change. Repeated tests of old and modern cars show that the difference in the change of velocity between identical cars often exceeds 1 m/s in impact conditions against rigid stationary objects. For the assessment of quality of the accident reconstruction a deviation below 1 m/s can be considered as good and below 1.5 m/s as acceptable.

Accident 1

The structural loading in Accident 1 exceeds the loading from the model validation test FWDB. While the test speed is almost identical the validation test loaded both longitudinals while the accident involved only one. Following that the capability to predict loadings beyond the FWDB test could not be assessed beforehand. When analysing the deformation characteristics the longitudinals in the

FWDB test were approx. 400 mm deformed. This deformation length was exceeded in the accident simulation after 32 ms. Up to that time and even approx. 20 ms later the velocity difference between the FE simulation and the actual test mainly stayed below +/- 1 m/s, see Figure 14. After this time the model became too stiff resulting in exceeding 2 m/s. The PC Crash simulations exceeded 2 m/s in the beginning and 4 m/s in the later part of the simulation. In general the PC Crash models are too stiff. However, the stiffness is needed for an appropriate accident kinematics. Furthermore the low sampling rate for the PC Crash simulations contribute to large deviation between test and simulation results.

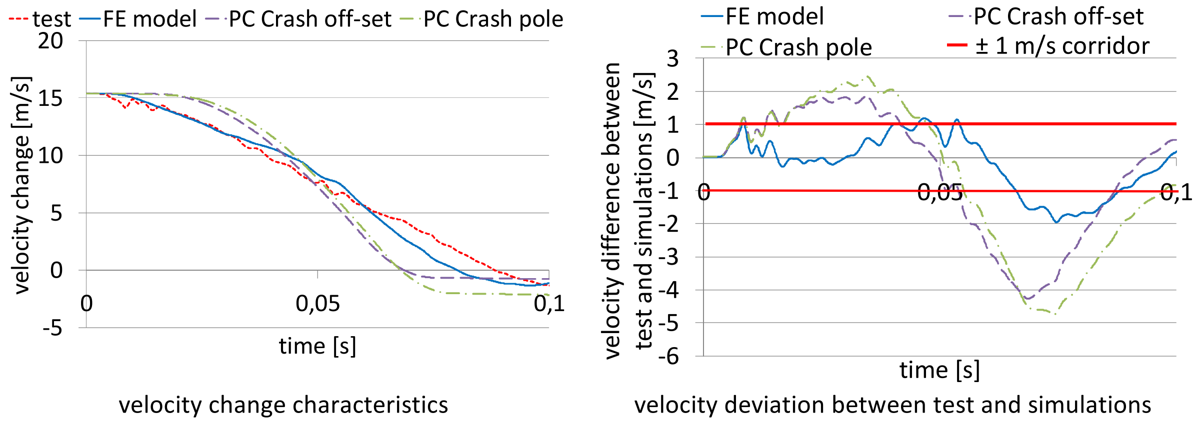


Figure 14: Velocity change comparison in Accident 1

Accident 2

In contrast to Accident 1 the structural loading in Accident 2 stayed within the validation range of the FWDB test. However, it was questionable whether or not the crossbeam stiffness, that largely contribute to the crash performance in the centre pole impact while the influence is less in the FWDB test, was modelled adequately. The comparison of the deformation pattern as well as the pulse and velocity change indicates good correlation also for the crossbeam, see Figure 15. Even though it sounds sensible that the cross beam is an important factor in the investigated pole impact it has to be mentioned, that the typically cross beam is not designed to withstand heavy bending loads. Due to the centred impact Euler buckling occurred and the resistance of the cross beam decreased to a low level that did not affected the crash pulse. Therefore the good correlation could be a result of the geometrical fitting of the structures because the block building mechanism and the inboard bending of the longitudinals seems to be the most important factor in this accident. The simulation velocity change did deviate from the test velocity change less than 1 m/s.

For the PC-Crash simulation there seems to be an issue of the stiffness of the model. In order to avoid that the model runs through the pole the stiffness characteristics needed to be modified in a way that no rebound was observed.

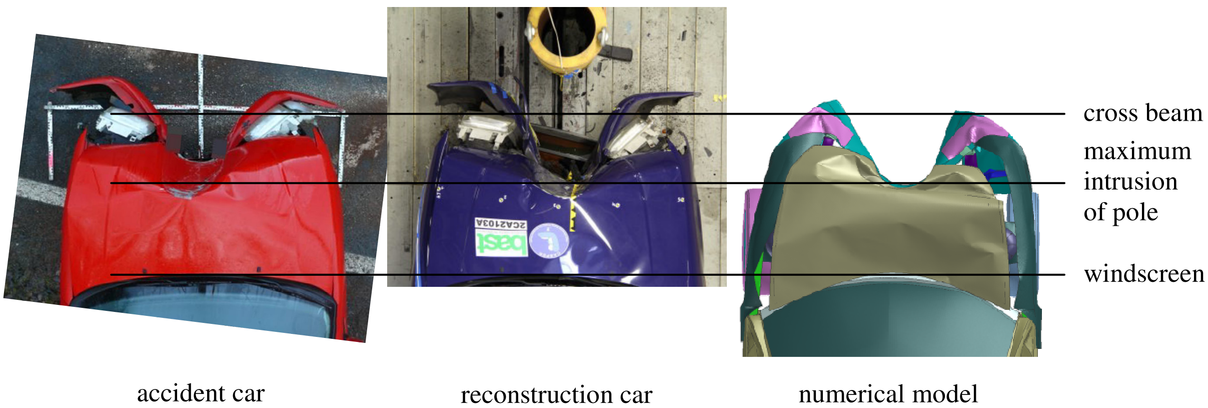


Figure 15: Comparison of deformation pattern of accident 2

For both simulations the time axis was shifted by 7 ms in order to obtain a better fit with the experimental reconstruction. This shift appears to be eligible as the first milliseconds of the crash are mainly defined by bumper and soft padding for pedestrian protection that is not represented in the FE model, Furthermore t0 seems not to be important for the injury causation. The shift was conducted visually by making the parts above and below the test curve virtually of the same size.

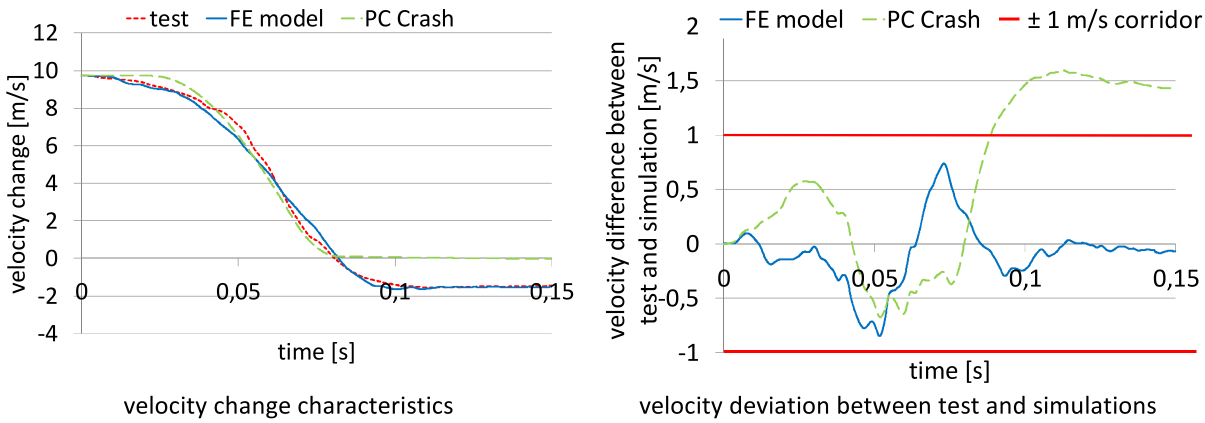


Figure 16: Velocity change comparison in Accident 2

CONCLUSION AND NEXT STEPS

In order to improve the insight into single accidents numerical accident reconstructions using Human Body Models would be beneficial. However, using OEM full FE models is normally not an option because these models are not available and are often incompatible between different brands because car manufacturers are using different tools. A solution could be the use of FE Parametric Car Models that are adopted to represent as good as possible the crash opponents.

As a first step one Parametric Car Model was adopted to an actual car that was used in two different experimental frontal impact accident reconstructions. For the adaptation geometrical information and the result from one published crash test was used. The two accident reconstructions were numerically repeated using the adopted parametric car model. However, only structural models without occupants were used.

In general the two numerical simulations indicate sufficient replication of the crash pulse between experimental and numerical accident reconstruction, i.e., deviation of the velocity change curve was for most of the time within general accepted limits. However, it is unclear how the observed deviations will influence the occupant output.

In parallel to the Parametric Car Model approach PC Crash simulations using the stiffness approach were conducted. They were proven to deviate from the experimental crash pulse too much and to deliver the output with a too low sampling rate.

In the next steps occupant models will be added in order to investigate the influence of deviations on the occupant outputs and to compare dummy readings between experimental and numerical accident reconstruction. Furthermore the Parametric Car Models need to be developed further to be suitable for other impact configurations than frontal impact.

ACKNOWLEDGEMENTS

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Pregnant Occupant Model with a Fetus: ‘Expecting’

B Serpil Acar

Loughborough Design School, Loughborough University, Leicestershire, LE11 3TU, UK

Abstract - Detailed anthropometric data of pregnant women have been collected and used in the development of a computational model of the pregnant occupant model ‘Expecting’. The model is complete with a finite element uterus and multi-body fetus, which is a novel feature in the models of this kind. The computational pregnant occupant model has been validated and used to simulate a range of impacts. The strains developed in the utero-placental interface are used as the main criteria for fetus safety. Stress distributions due to inertial loading of the fetus on the utero-placental interface play a role on the strain levels. Inclusion of fetus model is shown to significantly affect the strain levels in the utero-placental interface. This series of studies has led to the design of seatbelt features specifically for the pregnant women to enable them use the seatbelt correctly and comfortably.

Keywords Pregnant, occupant, fetus, crash, modeling, safety, ‘Expecting’.

NOTATION

ATD Anthropomorphic Test Device
UPI Utero-placental Interface
FE Finite Element

INTRODUCTION

Car occupants are legally required to wear seatbelts in many countries both as drivers and passengers. Pregnant women are not exempt from this rule. Each year, 131.5 million babies are born in the world. Potentially, 131.5 million pregnant occupants travel as passengers or drivers in vehicles, which are not designed to take into account their anthropometric differences and vulnerability. The level of exposure of pregnant women who experience an automobile accident is on the increase. It has been shown that road traffic accidents are the leading cause of accidental fetus mortality [1].

Wearing a seatbelt is shown to be a problem for a pregnant occupant [2]. During pregnancy a woman’s body undergoes a considerable change in size and shape, which can prevent her correctly wearing the safety belt during travelling in a road vehicle. Pregnant occupant anthropometry is the key to improving the positioning of the seat belt correctly around the pregnant woman’s altered body shape.

The presence of a fetus, along with the unique geometry of the pregnant woman, makes them a different group of occupants [3]. In the mid 90’s a pregnancy insert for the Hybrid III small female is developed to explore the effect of loading of vehicle safety systems on the approximately 28-week pregnant occupant [4]. This physical model included a urethane fetus which fitted inside a urethane casing that fitted inside a urethane uterus. A second-generation physical model of pregnancy insert is developed [5] which has more realistic anthropometry however it has neither a placenta nor fetus instead the uterus is filled with fluid. A computational model to represent a pregnant driver is developed [6], combining a FE model of uterus, without fetus, within an existing 5th percentile female occupant model available in the MADYMO package.

Another model named ‘Expecting’ which represents a 5th percentile female at around the 38th week of pregnancy is developed at Loughborough University [7]. The model is complete with a finite element uterus and multi-body fetus, which is a novel feature in the models of this kind, is integrated into an existing MADYMO female model to incorporate pregnant female anthropometry. The model is validated by using rigid bar impact and belt loading tests [7] since obtaining volunteer data using pregnant women in crash tests, however low speed it may be, is not practical.

The model, 'Expecting', has been used to simulate a range of impacts of increasing severity of Δv of 15kph to 35kph. Safety of pregnant driver when she was completely unrestrained, restrained with a three- point seat belt only, and restraint with a three-point seat belt and an airbag, have been investigated. The model has been further used in a variety of vehicle crash scenarios to demonstrate the importance of interior designs.

This paper focuses on a series of studies led by the author to highlight the importance of including the fetus within uterus of pregnant occupant models and the contribution of 'Expecting' in investigations and design, to improve safety for the fetus.

METHODS

The methodology covered in this section summarises the procedures of data collection for appropriate representation of pregnant women's anthropometry and the development of the pregnant woman model 'Expecting', vertical drop tests of the uterus model with and without fetus model, and crash simulations with the 'Expecting' with fetus and without fetus. Furthermore, it explains the procedures followed to investigate the difference between correct and incorrect seatbelt wearing for pregnant occupants.

Measurements of pregnant women

As the first step of a series of investigations, anthropometric measurements were recorded from pregnant women. The anthropometric measurements were selected for their applicability to the vehicle design process, and for understanding the changes in physical size and shape that occur during pregnancy.

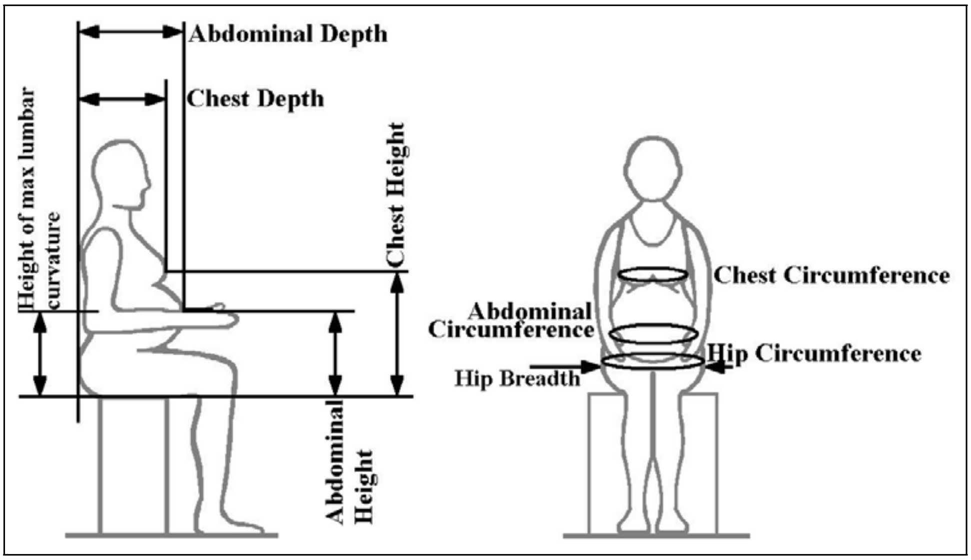

Figure 1. An illustration of the anthropometric measurements: Trunk region (Abdomen, chest and hips). Measurements and figures adapted for pregnant women from standard measurements in DTI, Adultdata, [8].

The measurements used the standard postures and procedures, as in [8] and [9], but were adapted where necessary to suit the pregnant body. For example the waistline diminishes during pregnancy so the abdominal circumference was recorded at the point of maximum circumference, rather than at the waistline (point of minimum circumference). 49 measurements of 107 women were recorded. The full measurement details and analysis can be found in [3]. As an example trunk region measurements are illustrated in Figure 1. Pregnant women were recruited in two locations in the United Kingdom. Over 800 pregnant women also completed a questionnaire to identify problems of pregnant occupants. The questionnaire findings are not in the scope of this paper although they are used to understand the need for specific measurements and interactions [2]. Volunteers wore light clothing and removed their shoes, and the equipment used included weight scales, a stadiometer, a digital vernier caliper, a tape measure and an anthropometer.

The Pregnant Occupant Model: 'Expecting'

'Expecting', the computational pregnant occupant model, embodies the complexity of pregnant women's anatomy and anthropometric details based on 49 measurement sets of data from 107 pregnant women volunteers [3]. A detailed multi-body representation of a fetus within a finite element uterus model is also integrated into the model. The model is placed within a typical vehicle interior model, consisting of a seat, vehicle floor, pedals, bolsters and steering wheel as shown in Figure 2(a), in the multi-body/finite-element software package MADYMO [10]. The finite element uterus model is built in accordance with the fetus dimensions and configuration controlling the dimensions of the uterus to provide a snug fit around the fetus to represent the 38 weeks of pregnancy as shown in Figure 2(b). The multi- body fetus model is composed of 15 rigid bodies representing the various anatomical regions of the fetus interconnected by kinematic joints. A finite element layer of fat encloses the outer surface of the uterus. A total fetal mass is 3.3kg and the resulting total mass of the uterus with the placenta and the fetus is nearly 4.60 kg. Further details of the multibody fetus model development can be found in [11]. Further details of the pregnant occupant model development and validation can be found in [7]. Simulations representing various crash scenarios are conducted with the 'Expecting'.

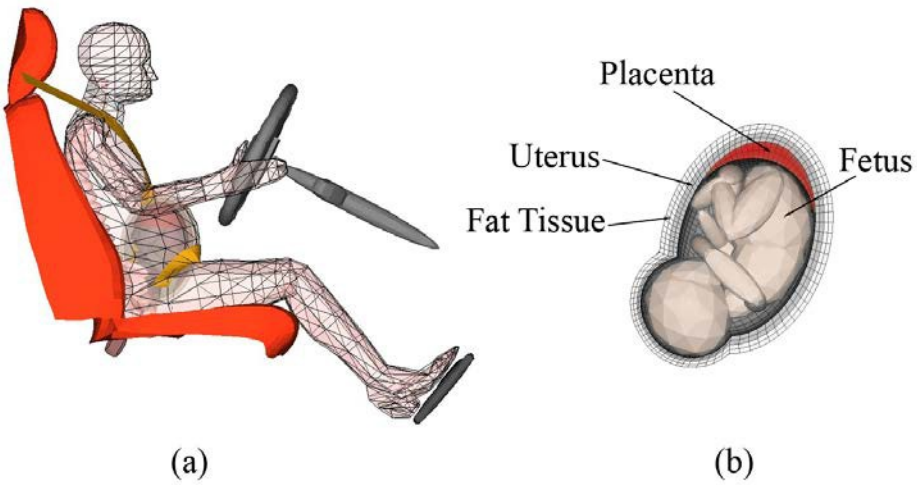

Figure 2. The pregnant occupant model 'Expecting' (a); uterus, placenta and fetus in 'Expecting' (b).

Vertical drop tests and crash tests with and without the fetus

Previous computational pregnant occupant models were designed without a fetus. A study of vertical drops of a simplified fetus and uterus model onto a rigid flat surface at different angles reported that the effect of impact on the uterus is independent of the fetus [12]. The uterus model of 'Expecting' and an identical uterus model without the fetus are used to repeat the drop tests conducted in earlier studies in the study above to investigate the effect of the fetus on the strains on utero-placental interface (UPI).

In addition, a version of the 'Expecting' model without a fetus is developed in which the entire uterus is filled with the amniotic fluid. 'Expecting', the pregnant occupant model and its without-fetus version are used in a number of frontal crash test simulations to investigate the contribution of the inclusion of a fetus on the strains generated at the UPI (Figure 3). Details of the vertical drop tests and crash tests with and without the fetus can be found in [13]. Maximum von Mises equivalent strain levels in uterus at the UPI are determined for with-fetus and without-fetus models to assess the possibility of placental abruption.

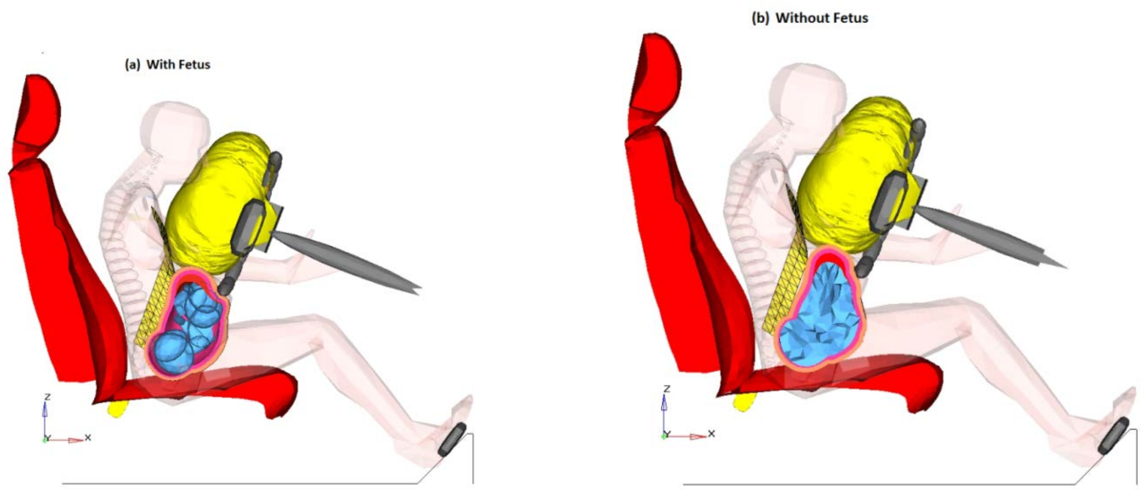

Figure 3. Typical frontal impact responses of the model with and without fetus for 30 kph at 105ms of the impact.

Crash tests for correct and incorrect use of the seatbelt during pregnancy

Hybrid III 5th percentile female ATD with the MAMA2B pregnancy conversion, the only commercially available device capable of representing the pregnant female was used for a series of Hyper-G sled tests to assess the effectiveness of correctly and incorrectly worn seatbelts.

A sinusoidal pulse with a delta-v of 50km/h was used, similar to the regulatory requirements for seat belts [15]. Two types of test were completed; a seat only style test (just the car seat and seat belt system with no pre-tensioners fired), and a buck style test (vehicle buck mounted on the sled with airbag and seat belt double pre-tensioners deployed). The driver's seat was used in all tests. The tests had the lap portion of the seat belt positioned correctly (across the hips and underneath the abdomen) and incorrectly (across the middle of the abdomen).

RESULTS AND DISCUSSIONS

The analysis of the data collected from pregnant women revealed that the key regions of physical change during pregnancy are the chest, abdominal, and hip regions. The size of the chest, abdomen and hips of a pregnant woman can be so enlarged during pregnancy that these measurements exceed the equivalent measurements of the large 95th percentile male by a considerable amount. The abdomen region for males, non-pregnant women and pregnant women are shown in Figure 4. Details of the differences for other regions can be found in [3] and prove that pregnant women form a new population that was not considered in modelling before. Hence it is important to use the measurements of pregnant women in models that represent them.

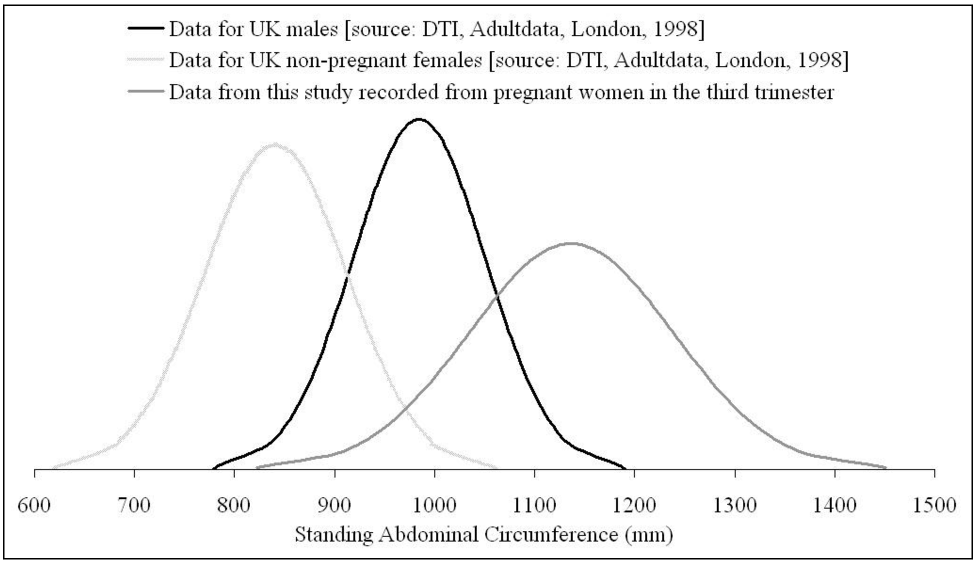

Figure 4. Standing abdominal circumference: A comparison of pregnant women in the third trimester against data for UK males and non-pregnant females.

'Expecting' incorporates the anthropometric details of pregnant women. Regarding the inclusion of the fetus, in general vertical drop tests of the uterus with fetus caused higher strain levels than without fetus model at angles of 0°, 30°, 90°. More importantly, at 180° drop, where the placenta is at the leading end of the uterus in the impact simulations, the highest strains on the uterus are observed at the UPI. In this case, significantly high (almost four times as much) strains in the model with fetus are observed. Crash simulations confirmed the importance of including the fetus. Full drop test and crash test results can be found in [13]. As an example, the airbag only case, where the seat belt is not worn during the impact of 15- 35 kph the strains at the UPI are shown in Figure 5, and proves how critical it can be in cases of 20 and 25 kph impacts. This demonstrates that when the fetus is included in the model, the placental abruption risk emerges at a crash speed of 20 kph, whereas the without fetus model shows that the placental abruption risk begins at a higher crash speed of 30 kph. Without the seatbelt, it is clear that the contribution of the fetus on the maximum strains at the UPI is much more pronounced and the placental abruption risk is found to be higher. The mass of the fetus plays a significant role in the behaviour of 'Expecting', the pregnant occupant model. These results clearly demonstrate that the fetus changes the entire dynamic response to impact.

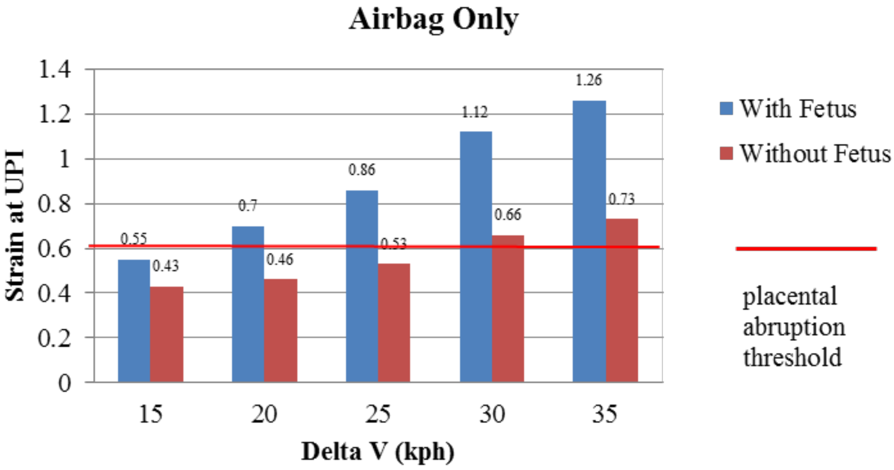

Figure 5. Strain levels at the UPI of the pregnant occupant model with and without fetus for airbag only case

Simulations of various crash scenarios with ‘Expecting’ have suggested that the fetus fatality risk can increase with speed [7]. Results have also suggested that driving with full restrains, where both the seatbelt is worn and airbag is active, can provide the safest conditions for the pregnant occupant.

On the other hand, the crash tests using the pregnant occupant ATD, MAMA2B , have highlighted the importance of wearing the seatbelt ‘correctly’. The correct position for the seat belt in pregnancy is with the shoulder section passing across the shoulder, between the breasts, and around the abdomen, and the lap section passing across the hips and underneath the abdomen. This seat belt position is recommended by many authorities, including the UK Department for Transport [16], the American College of Obstetrics and Gynaecology [17] and the National Highway Traffic Safety Administration [18].

The traces for abdominal pressure (KPa) comparing the lap belt correctly positioned across the hips according to the guidelines against the lap belt incorrectly positioned across the abdomen are shown in Figure 6. Full experiment results can be found in [19]. It is clear that the lap belt positioned across the abdomen gives a much higher pressure indicating higher risks, than with it positioned across the hips. The peak pressure for the incorrectly positioned lap belt over the abdomen was one quarter to one third greater in comparison to the correctly positioned lap belt over the hips.

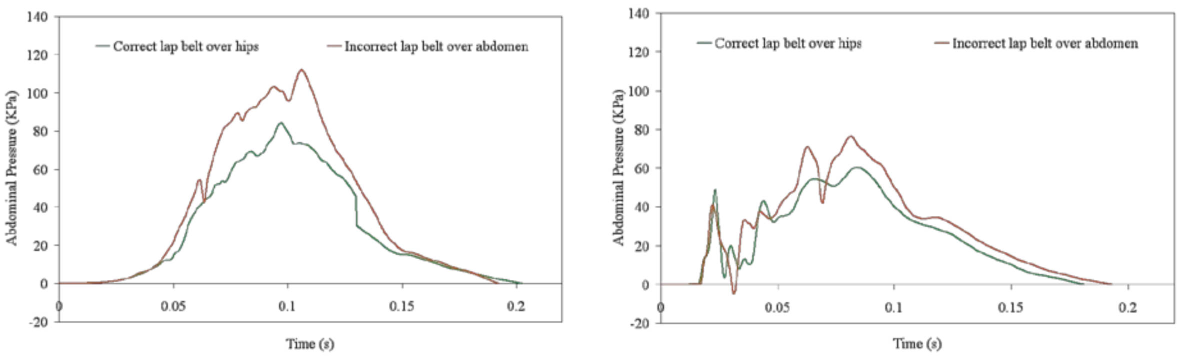

Figure 6 Abdominal pressure (KPa) traces for seat and buck tests: Comparison of correct lap belt position across the hips versus incorrect lap belt position across the abdomen.

The visual material from the simulations with 'Expecting' supports that in the investigated cases, the maximum strains in uterus at the placental location seem to be mainly due to steering wheel loading for the full-frontal impacts, whereas maximum strains in overall uterus occur mainly due to lap belt loading. As lap belt section of the seat belt tends to ride up towards the abdomen during driving [2], it is vital to wear it as correctly as possible in accordance with the guidelines.

Anthropometric data from pregnant women, the computational pregnant women model 'Expecting', simulation of the accidents and the need to wear the seatbelts correctly led the authors to design a commercially viable device to solve the problem. The devise is applied to the conventional, industry standard three-point seat belt and it does not interfere with its functionality.

Static and dynamic user tests of the device were conducted with pregnant women at Loughborough University with excellent results. During the user tests, pregnant women assessed the device's comfort and ease of use as well as its functionality. Sled tests at Thatcham Crash Test Laboratory has also taken place and confirmed that the device keeps the three-point seatbelt always where it should be.

CONCLUSIONS

The work described in this paper is a part of a comprehensive research program at Loughborough University to improve fetus safety using a computational pregnant occupant model. First the features of the pregnant women were identified. Then a computational pregnant occupant model with a finite element uterus model and a fetus were developed. The model also incorporates the geometric features of a 5^{th} percentile female at around the 38^{th} week of gestation. Vertical drop tests of the uterus and crash tests of the model 'Expecting' have been conducted. In conclusion, the findings of the research suggest that the fetus should be included in the uterus in pregnant woman models to take into account its effect in more realistically simulated dynamic behaviour of pregnant occupants.

Simulations with 'Expecting' and sled tests with the commercially available physical model MAMA2B show that the correctly worn seatbelt is essential for the safety of pregnant occupant and fetus, and further systems that enable the correct use without interfering with the existing restraint systems are beneficial.

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A study of long bone fractures via reconstruction of pedestrian accident using Multi-body system and Lower Extremity FE model

Bingyu Wang*, Jikuang Yang**, Otte Dietmar***

* Research Center of Vehicle and Traffic Safety (VTS), State key Laboratory of Advanced Design Manufacturing for Vehicle Body, Hunan University, Changsha, 410082, China

** Department of Applied Mechanics, Chalmers University of Technology, Gothenburg 41296, Sweden

*** Accident Research Unit, Medical University of Hannover, Hannover, 30625, Germany

Abstract: This study aimed at prediction of long bone fractures and assessment of lower extremity injury mechanisms in real world passenger car to pedestrian collision. For this purpose, two pedestrian accident cases with detail recorded lower limb injuries were reconstructed via combining MBS (Multi-body system) and FE (Finite element) methods. The code of PC Crash was used to determine the boundary conditions before collision, and then MBS models were used to reproduce the pedestrian kinematics and injuries during crash. Furthermore, a validated lower limb FE model was chosen to conduct reconstruction of injuries and prediction of long bone fracture via physical parameters of von Mises stress and bending moment. The injury outcomes from simulations were compared with hospital recorded injury data and the same long bone fracture patterns and positions can be observed. Moreover, the calculated long bone fracture tolerance corresponded to the outcome from cadaver tests. The result shows that FE model is capable to reproduce the dynamic injury process and is an effective tool to predict the risk of long bone fractures.

Key words: lower extremity FE model, long bone fracture, pedestrian accident, injury reconstruction

1 INTRODUCTION

As vulnerable road users, pedestrians are injured frequently in vehicle accident due to lack of outer protective equipments. Every year a lot of unprotected pedestrians are injured or died in road traffic accidents. According to the report of 2010, in European Commission, 6004 pedestrians were killed, accounted for 20% of all fatalities in the traffic accident [1]. Statistic analysis of traffic accidents indicated that lower extremity is the most frequently injured body region, accounting for 32.8% of all injuries [2]. Although rarely fatal with an AIS (Abbreviated Injury Scale) rating ranging from 1 to 3, lower limb injuries will cause long-term impairment and even disability, resulting huge social and economical cost [3].As one of the most common injury modes in car-pedestrian crashes, long bone fracture is mainly attributed to the excessive bending moment caused from the contact between lower limb and car front end structure [4]. The statistical data showed that bumper and bonnet leading edge were the main cause of long bone fractures. It indicated that about 82% of lower leg serious injuries were caused by bumper, however, 47% and 32% of thigh AIS2+ injuries were attributed to bumper and bonnet leading edge, respectively [5].

Over past decades, many cadaver tests have been done to determine the tolerance of long bone fractures in terms of impact force and bending moment. It was reported that femur shaft fractured at peak impact forces from 3 to 10kN, and bending moments at about 320Nm [6]. Tibia fractures were reported at peak forces from 2.5 to8kN, and at bending moments of 280Nm for females and 320Nm for males [4]. Most of those results are derived from 3-point bending test on long bone mid-shaft. However, the studies by Kerrigian[7] and Ivarsson [8] showed that response of long bone to lateral-medial bending depended significantly on loading positions. In other words, existed long bone injury criteria are controversial to assess the protect performance of designed cars since most of them were developed according to published cadaver tests.

FE models of human body lower limb can be used to vividly show process of long bone fractures during collision and the calculated parameters like stress and strain can predict injuries based on accepted failure criteria. FE models of lower extremity were developed and validated against published cadaver tests, and then these models were used to study lower limb injury tolerance and even to assess the design of protective devices [9-11]. However, owing to the limitations of cadaver specimens, the cadaver tests cannot truly reflect the dynamic response of lower limb. Moreover, in real car-pedestrian accidents, the injury patterns and loading conditions are more complex than those used in published literature [12]. Therefore, accident reconstruction by using the in-depth accident investigation data is an effective method to calculate injury related parameters at varying impact conditions for evaluation of FE model [13].

The objective of current study is to investigate the long bone fracture risk via accident reconstruction using FE model. Two pedestrian accident cases with long bone fractures were reconstructed using multi-body system model. Then a validated lower limb FE model was used to predict long bone fractures by calculating injury related parameters, such as von Mises stress and bending moment. The results are analyzed and discussed in terms of lower limb failure mechanics and injury risks.

2 METHODOLOGY AND MATERIALS

2.1 Selected accident cases

According the study of Yang[4], about 85% of the cases the pedestrians were hit laterally, and the main accident car type was passenger car. Thus, two pedestrian cases with lower limb long bone fractures were selected in current study. The X-ray scans results were used to clarify the long bone fractures. At last, one case with detail lower leg bone fracture in GIDAS (German In-depth-Accident Study) and the other one with detail femur fracture and fibula proximal fracture in IVAC (In-depth Investigation of car accidents in Changsha) were used to conduct simulation analysis.

Case1: A car was travelling in the road with the speed of 50km/h from north to south. Suddenly, the driver found a male pedestrian was walking across the road from east to west. The driver took emergency braked with a skid mark 5~10m before the car hit the pedestrian. The pedestrian was thrown away and fell down on the ground.

Case 2: A passenger car was running near the middle line from east to west. Because it was dark and the weather was drizzle, when the driver noticed that the pedestrian was stop in front of the car, it was no time for him to take measure to avoid the accident. The driver braked emergently but still struck the pedestrian. The detail information about the cases was listed in Table 1.

2.2 Pedestrian and passenger car MBS model

Vehicle models were developed based on drawings of production cars of the same model and year as involved in the accident. The outer surface of the accident car was represented by ellipsoids. Moreover, the geometric parameters referring to the car front shape were used to control the development of car front structure [14]. The contact stiffness of bumper used the same value in the bumper structure of the two accident cars, while the bonnet edge stiffness varied from midsection position to side frame position due to the existence of head lamp. The stiffness characteristic curves (Fig.1) were defined using Euro-NCAP (New Car Assessment Programme) test results obtained from similar car models [15].

In current study, a 50th percentile male pedestrian dummy developed and validated by Yang et al [16] was employed as the reference dummy. The model consists of 15 ellipsoids that represent the main body parts, which are connected by 16 spherical joints. The frangible leg model in this model is used to predict the bone fracture phenomena if the impact force or bending moment exceed the tolerance level. Fig. 2 indicates the MBS car and pedestrian models using in current simulation. This model was scaled to represent the victims based on the height and weight of each involved pedestrian using the GEBOD program.

Table1 Summary of the cases information

Case No	Pedestrian			Vehicle				Injury Description	AIS
	Age	Height /cm	Mass /kg	Type	Mounting Mass/kg	Dimension L×W × H mm/mm/mm	Impact velocity /km.h^{-1}		
1	65	174	67	Passat B3	1250	4580×1720×1460	37.1	Tibia shaft open fracture Fibula shaft fracture	3 2
2	50	174	70	Jetta A2	1480	4385×1665×1410	26.6	Right femoral intertrochanteric fracture Fibula proximal fracture	3 2

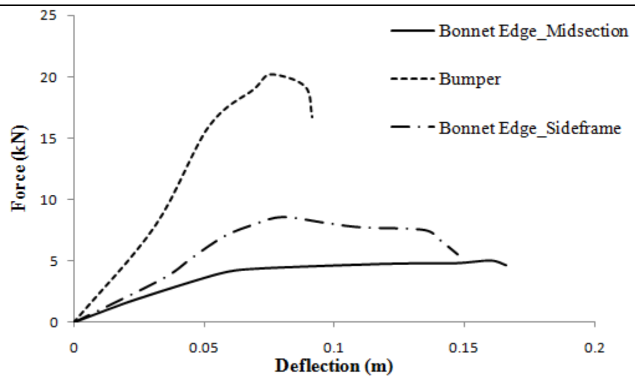


Fig.1. Contact characteristic of car front structures

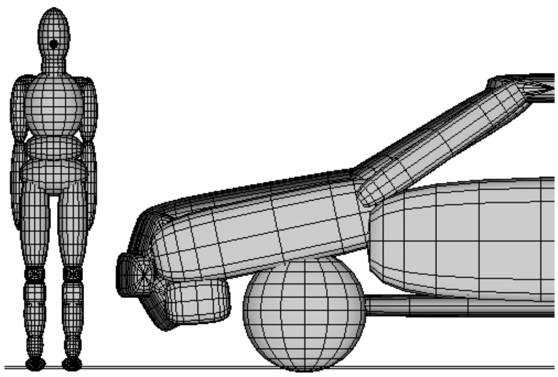


Fig.2. the baseline car-pedestrian Multi-body system model

2.3 Accident reconstruction by means of MBS method

Firstly, the code Pc-Crash was used to reproduce the accident cases in order to define the collision boundary conditions in Madymo, such as the moving speeds of accident car and pedestrian as well as deceleration of car. The orientation and position of victim in Madymo were approximated by associating pedestrian injuries with impact points on the car. Then, parametric study was performed concerning vehicle's velocity and driving direction as well as pedestrian's speed and stance to determine the best correlations with the scene sketch from in-depth on-site investigations.

The final results agreed with the real accident record, including impact locations on the car, injuries of human and relative position between car and pedestrian at post phase of accident. These were restrained to conduct the research of next step. A friction coefficient between car and ground was considered due to the emergency brake before impact. The values of 0.6 and 0.7 from PC-Crash simulation were assigned to case1 and case2, respectively. While, the fiction coefficients between pedestrian and ground as well as pedestrian body parts with car were defined as 0.6 and 0.3, respectively.

2.4 Development of FE model for lower limb injury reconstruction

The car FE model was developed based on the detail geometry of front structure of each accident car. Because the main purpose of this study is investigate the long bone fracture of lower extremity, the front structure parts involving in lower limb injury were remained, such as bumper system, head lamp, bonnet edge and bonnet. A concentrated mass node representing the car curb weight was attached at the mass gravity position to the front structure via rigid contact method. The material properties of car front structure derived from validated similar cars and adjusted according to the stiffness used in MBS car model.

The lower limb FE model used in current simulation derived from HUMOS2(Human Model for Safety) full human body model, which is developed based on European 50th percentile adult male. The lower extremity FE model was refined and validated to evaluate the performance of a bumper [10]. In order to simulate the real accident and reproduce the friction between shoe and ground, a FE shoe was attached to this model. In addition, the pelvis was added in the original FE model to evaluate the femur proximal injuries. The ligaments and muscle around hip joint were simply represented by discrete elements. The whole model consists of 71 components and 31,205 elements. The baseline FE model for simulation of impact between car front structure and lower limb was developed and shown in Fig. 3. Considering the influence of upper body inertial force on the kinematic of lower extremity during collision, a preload of 400N was applied to the lower limb to represent the weight of upper body.

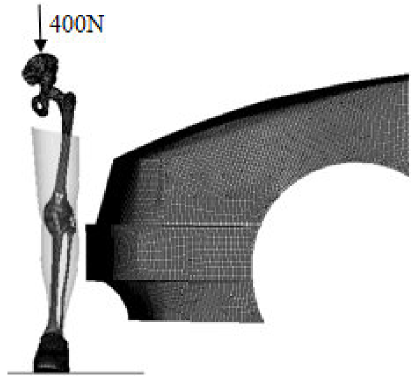


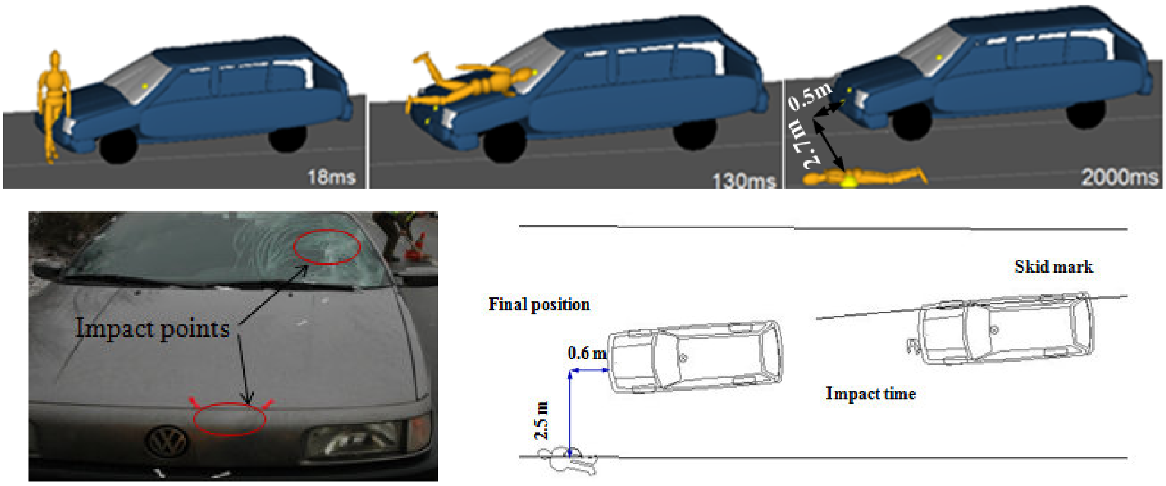
Fig.3. The baseline FE model between car front structure and lower limb

Then, the results from MBS reconstructions were used as the boundary conditions in the setup of FE simulations. Because of the differences of weight between victims and 50th percentile European male, the preloads were adjusted to 350N and 335N in case 1 and case 2, respectively. Several sections were defined in the lower limb FE model to record the section bending moment of long bones during collisions. Long bone fractures were simulated by the elimination of elements through setting ultimate strain.

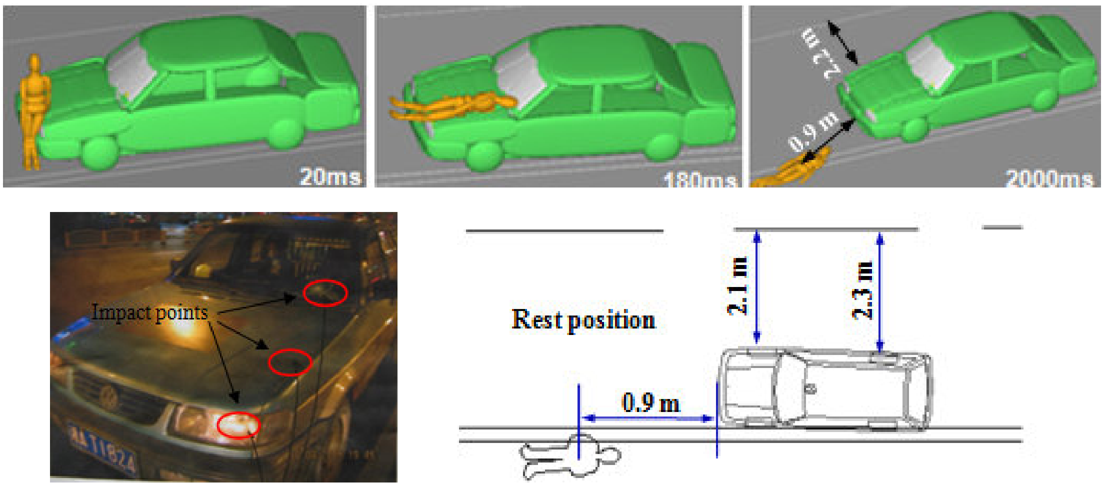
3 RESULTS

3.1 Pedestrian kinematic and rest position from MBS simulation

Fig. 4 (a) indicates the kinematics of pedestrian and the data from on-site investigation of case 1. The first impact happened between the left lower leg and the bumper, followed by the thigh impacted with bonnet leading edge at 18ms due to the inertial of upper body. Then, the upper body rotated around the bonnet leading edge, causing the head contacted with windshield at 130ms. Furthermore, the pedestrian was thrown forward and fell on the ground at 2000ms. Comparing the impact points and rest position of car and pedestrian from simulation and real record data, the simulation results have a good agreement with the in-depth on-site investigation data.



(a) Case 1



(b) Case 2

Fig.4. Pedestrian kinematics and final position comparing with real record data

It can be seen clearly pedestrian dynamic collision process of case 2 in Fig. 4(b). The first contact occurred between bumper and knee joint area, followed by the thigh-to-left head lamp contact at about 20ms. Furthermore, the upper body wrapped backward around car, leading the chest impacted with the rear of bonnet and head contact against windscreen at 180ms. Then, the whole body was thrown off the bonnet, fell and slid on the ground. At 2000ms, the pedestrian stopped at the final position and the simulation finished. The impact points and rest position of car and pedestrian from on-site investigation were also shown in Fig. 4(b). The reconstruction results showed good accordance with the record data from real accident through comparing the impact points and final position.

3.2 Output of kinematics from MBS reconstruction

In the MBS reconstruction, pedestrian lower limb injuries were evaluated in terms of the calculated impact force. Output impact forces and recorded injuries were compared in table2

In the case 1, the peak force in the left frangible joint reached to 5.2kN, which exceeded the reference value of 4kN. This value was set as an indicator of fracture risk of tibia. The impact force between bumper and tibia was 5.1kN, which was higher than tolerance level as well.

In case 2, the interface contact force between bumper and up section of lower leg was 3.8kN, which did not reach the tolerance of tibia but exceeded the tolerance of fibula. According to the study of Levine [17], the fracture force of fibula was about 0.44kN. In the simulation of case 2, pedestrian thigh proximal impacted with the bonnet leading edge and the corresponding contact force was 5kN, which indicated 20% risk of femur fracture [18]. The output parameters showed good agreement with the hospital record injuries in both cases.

Table 2 Comparison between output parameters and hospital record data

	Simulation	Injury Record
Case2	Bumper and up section of lower leg is 3.8kN (0.44kN as the reference fibula fracture force)	Fibular head fracture
	Bonnet leading edge and proximal femur is 5kN (indicates 20% risk of femur fracture)	Femur intertrochanteric fracture

Table 3 Initial boundary conditions for FE reconstruction

Items		vehicle		pedestrian	
		Case1	Case2	Case1	Case2
Linear velocity(m/s)	V_x	10.3	7.388	0	0
	V_y	0.72	-0.0354	1.94	0
Angular velocity(rad/s)	ω_z	0.2	-0.043	0	0

3.3 Long bone fractures predicted by FE model.

The determined velocities and orientations of pedestrians and cars from MBS reconstruction were employed as the boundary conditions in the FE model. Table 3 indicates the initial conditions for FE reconstruction. In the FE model, the process of long bone fracture was illustrated by means of output animations. Bending moments through the sections defined in the lower extremity were recorded as fracture index to evaluate the long bone injuries. Observed von Mises stress was used to clarify the long bone fracture and to detect the accuracy of long bone mechanical property as well.

The long bone fractures and recorded moment-time curves of case 1 are shown in Fig. 5 and Fig. 6, respectively. Combining the dynamic response process and output moment, the causation and injury mechanisms of lower leg bone was identified. The pedestrian was walking and left leg was rising when the impact happened, leading the bumper firstly hit the fibular head. Flesh and skin around this region was compressed and transferred the force to fibular head at the initial impact time of 2 ms. Thus, the whole fibula bending toward the lateral direction and the moment appeared as a negative value. Then, the whole bumper contacted with the fibula and the applied force move downward to the fibula proximal, causing the fibula and tibia began to bending toward medial direction and the moment of fibula and tibia shaft was expressed by means of positive value. With the function of impact force, the bending moment of fibula and tibia increased quickly. When the tensile stress on the non-loading side reached to fracture tolerance at the time of 9 ms, tibia shaft fracture occurred. At the fracture time, recorded moment reached to 310.8 Nm and von Mises stress was 145 MPa. Then, the bending moment of fibula increased to 21.4 Nm at the time of 10 ms. Fibula fracture occurred and von Mises stress reached to 145 MPa.

Fig. 7 indicates the dynamic process of long bone fractures of case 2. The bumper first hit the knee joint region. With the function of impact force, fibular head would move toward tibia. Stress concentration occurred at the contact surface between fibular head and tibia proximal. Fibular head fracture happened when the von Mises of fibular head reached to the fracture stress of 145.4 MPa at the time of 20 ms. At the initial of collision, the impact force passed from skin and flesh to femur distal, causing the femur bending toward lateral direction and the moment of femur neck indicated minus value, as shown in Fig. 8. After the fibular head fracture, the bumper impacted the tibia component and knee joint sustained a large valgus rotation and shear displacement. Then, the femur moved toward the hood leading edge due to the inertial function of upper body. While the head lamp impacted thigh proximal, impact force employed to the femur shaft. Then, the femur began to bending toward medial direction and moment of femur neck showed positive value. Owning to the constraint of hip joint, the moment of femur neck region increased quickly until 304.7 Nm. Fracture occurred at femur neck region and the von Mises stresses of femur cortical and spongy bone reached to 137.5 MPa and 9.4 MPa, respectively.

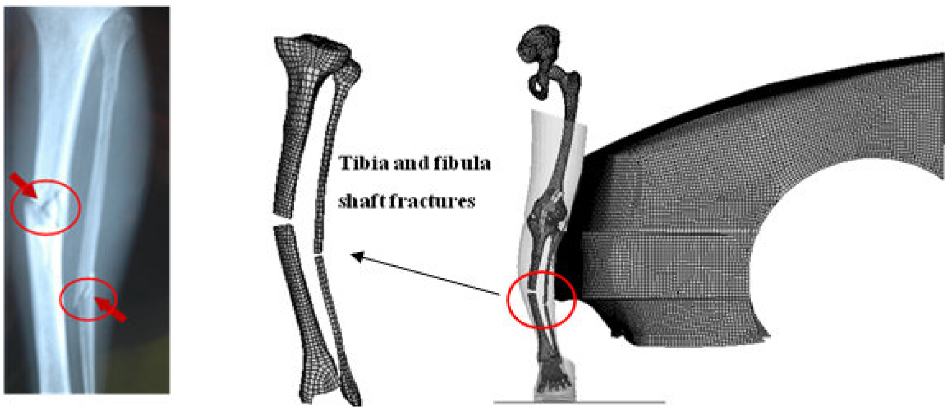


Fig.5. Comparison of long bone fractures between X-ray scanning and FE model simulation in case 1

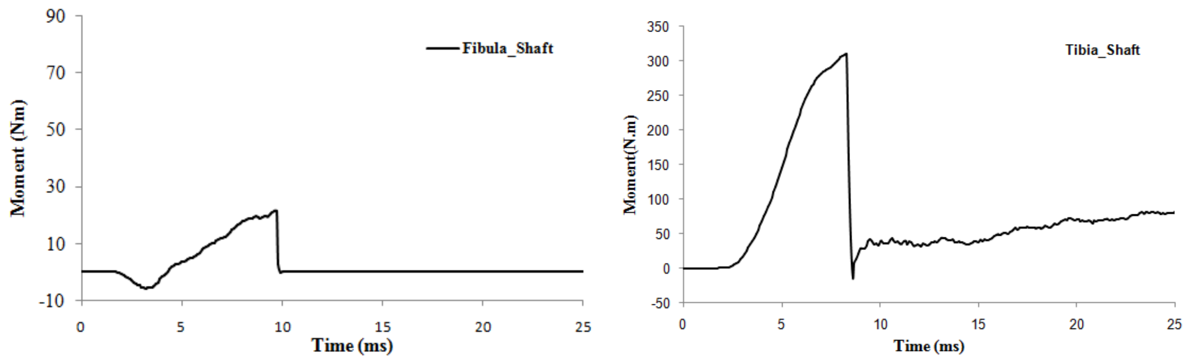


Fig.6. Moment-Time history of Fibula and Tibia from simulation of case 1

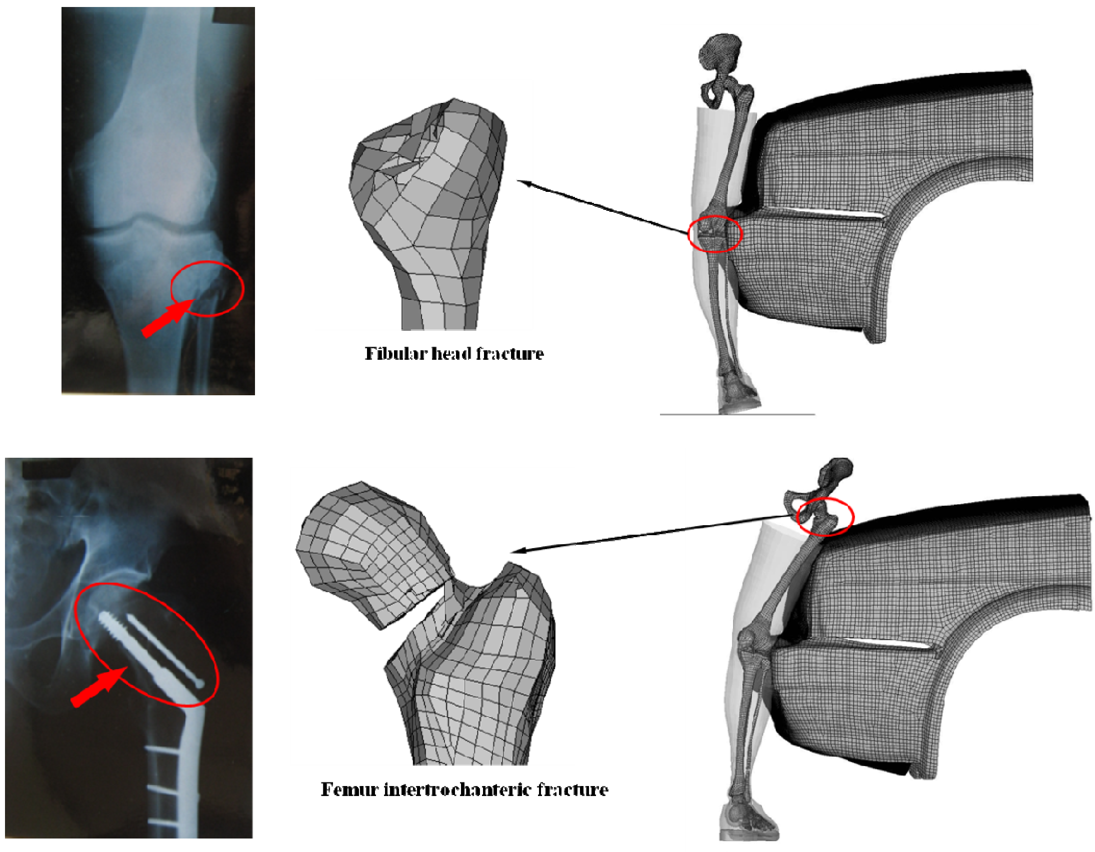


Fig.7. Comparison of long bone fractures between X-ray scanning and FE model simulation in case 2

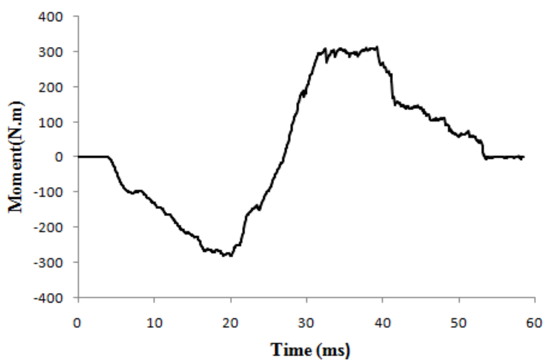


Fig.8. Moment-Time history of femoral neck from simulation of case2

4 DISCUSSION

In current study, two real-world pedestrian accidents were selected to investigate the long bone fractures which identified by X-ray scanning in hospital. The two victims were hit laterally by popular passenger car and the height of the pedestrians was closed to the height of 50th percentile European male, which represent the most common scenario of pedestrian accidents. Then, the selected cases were reconstructed through combination of MBS and FE methods.

The MBS reconstruction is able to show the human kinematic process during impact. In addition, it takes very little time to finish accident reconstruction. However, it cannot show the procedures and detail positions of lower limb injuries, which make it is difficult to indentify detailed injury mechanisms and develop injury criteria using MBS models.

The FE reconstruction can clearly show the progress and positions of long bone fractures. The dynamic response from FE model can be used to clarify the injury mechanism of long bone. Fibula proximal fracture is one common lower limb injury pattern due to the first impact usually happened between this region and bumper. In the FE injury reconstruction of case 1, it can be seen that fibula and tibia shaft fractures were attributed to bending moment caused by the impact force from bumper. In addition, tibia shaft fracture occurred before fibula shaft fracture indicates that fibula sustains more bending deflection than tibia when loading at bone shaft. Because of the restraint of knee ligaments and the friction force between shoe and ground, the dynamic responses of fibula and tibia shaft fracture process were similar to those of dynamic 3-ponit bending tests. Thus, to some extent the injury tolerance developed from pure tibia and fibula bending test could be considered as the injury criteria to predict long bone fracture. As indicated in case 2, the bonnet leading edge is the main reason causing femur intertrochanteric fracture. However, the fracture process of femur neck illustrates that it is not suitable to use dynamic 3-point bending tests to develop injury criteria of femur neck region.

Comparing the X-ray scans and fracture predicted by lower limb FE model, it can be seen FE model can generally reflect the fractures occurred in real world. The ultimate von Mises stress of fibula and tibia cortical predicted in the simulation is 145 MPa and the values for femur proximal cortical and cancellous are 137.5 MPa and 9.4 MPa. All the predicted ultimate von Mises stresses are in the corridor concluded by Takahashi et al [19]. The predicted fracture moment of fibula shaft is 21.4 Nm, which is slightly lower than the suggested fracture moment of 27 Nm [17]. In addition, the predicted fracture moment of tibia shaft was 310.8 Nm, which is close to the tolerance fracture at 312 Nm recommended by Kerrigan et al [7]. The predicted fracture moment of femur neck is 304.7 Nm. However, no available cadaver data can be used to define the tolerance of femur neck in pedestrian accident.

Information from in-depth accident investigation is very useful to validate the accuracy of reconstruction and as well as validate the biofidelty of Lower limb FE model by comparing the predicted long bone fractures and recorded injury data. It should be noticed that the fracture stress and moment obtained from simulation are only acceptable to predict long bone fractures in the same fracture locations. A large amount of pedestrian cases with different long bone fractures locations and impact conditions should be investigated and reconstructed via FE model to develop the bending strength threshold for long bones in different positions.

The disadvantage of current study is that the upper body was represented by a preload force, which cannot truly reflect the inertial function of upper body on lower extremity. In addition, it cannot simulate the mutual function between two legs. Therefore, it is necessary to develop the whole human body FE model and use the model to predict long bone fractures.

5 CONCLUSIONS

1. The lower extremity FE model has good biofidelity and can be employed to predict long bone fractures occurred in the real world accidents. It is an effective method to predict long bone fractures via reconstruction using combination of MBS and FE model. MBS method is used to reproduce the pedestrian kinematic and obtain the boundary conditions at collision. FE model is used to indicate the process and detail position of long bone fracture.
2. In-depth accident investigation is very important for the reconstruction of MBS method and validation of lower limb FE model. By comparing the long bone fractures from X-ray scanning and FE simulations, the biofidelity performance of lower limb FE model can be clarified.
3. Considering the discrepancy of specimens and boundary conditions, it is feasible to use validated FE model to predict long bone fractures. The predicted fracture moment of femoral neck is 304.7 Nm. The fracture moments for fibula and tibia shaft are 21.4 Nm and 310.8 Nm, respectively.

ACKNOWLEDGEMENTS

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Automated crash computation of passenger car accidents based on the GIDAS database

M. Wagner, L. Hannawald, H. Liers*

* Verkehrsunfallforschung an der TU Dresden (VUFO) GmbH, Semperstraße 2a, 01069 Dresden

Abstract

For the estimation of the benefit and effect of innovative Driver Assistance Systems (DAS) on the collision positions and by association on the accident severity, together with the economic benefit, it becomes necessary to simulate and evaluate a variety of virtual accidents with different start values (e.g. initial speed). Taken into account the effort necessary for a manual reconstruction, only an automated crash computation can be considered for this task.

This paper explains the development of an automated crash computation based on GIDAS. The focus will be on the design of the virtual vehicle models, the method of the crash computation as well as exemplary applications of the automated crash computation. For the first time an automated crash computation of passenger car accidents has been realized. Using the automated crash computation different tasks within the field of vehicle safety can be elaborated. This includes, for example, the calculation of specific accident parameters (such as EES or delta-V) for various accident constellations and the estimation of the economic benefit of DAS using IRFs (Injury Risk Functions).

NOTATION

E_{ges}	Overall Energy
m	Passenger car mass
EES	Energy Equivalent Speed
F	Force (Deformation)
s	Distance (Deformation)
E_{def}	Deformation Energy
E_n	Maximum Deformation Energy
S_n	Maximum Distance (Deformation)
EES_{voxel}	Energy Equivalent Speed of one voxel
$E_{voxel,k}$	Deformation Energy of one voxel

Motivation

Within the process of increasing the traffic safety many new driver assistance systems (DAS) are developed. Most often an accident scenario with the highest relevancy is identified and therefore a system is adapted to avoid an accident or at least to mitigate the accident severity. So far systems like the antilock braking system (ABS©) or the electronic stability program (ESP©) have helped to decrease the number of accidents or their severity.

With ambitions to have no road traffic fatalities in 2050 and to develop cars for autonomous driving the importance of testing DAS in regards to their actual performance in real accident scenarios, as well as the estimation of the benefit of such a system, is constantly increasing.

Therefore the DAS has to be assessed at least before the market launch, if not even before the launch of production. In the best case this is already done during the development process of the DAS.

Additionally a large number of realistic accidents with detailed information is needed to test the performance of DAS. Since the activation of a DAS most often leads to a change of the collision parameters (e.g. collision speed and constellation) of the participants, the necessity of a new reconstruction of the whole accident arises. Due to the fact that a manual reconstruction is time- and resource-consuming the only considerable way to assess DAS during the development process is to do so with an automated crash computation.

During a series of different projects the VUFO has started to develop an efficient tool, called Automated Crash Computation, which uses the information of real accidents provided by the GIDAS database.

Virtual Vehicle Models

The Automated Crash Computation uses virtual vehicle models with information about the EES which is available in the GIDAS database. The creation of such models has been explained in great detail in previous publications [1, 2]. For this paper only the main steps to create virtual vehicle models from the GIDAS database will be summarized.

These steps are the following:

1. 3-dimensional description of the deformation values of each car
2. Creation of a 3-dimensional vehicle model
3. Merging of the deformation information with the 3-dimensional vehicle model
4. Merging the 3-dimensional deformation vehicle model with information on the deformation energy
5. Merging all information from every energy vehicle model by car type

In the GIDAS database there are deformation values available for every deformed car. The single deformation values are coded in the database using standardized schemes for every car type. Figure 1 shows an extract of these schemes.

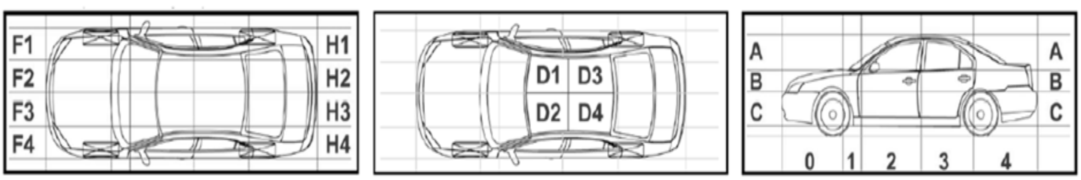

Figure 1. GIDAS schemes for car deformations

For each zone of the car a single deformation value (deformation depth) is coded. Therefore a linear interpolation between the values is done to extract a deformation line of the car. This concludes step number one.
The second step includes the creation of a 3-dimensional vehicle model. For this a pre-defined 3-dimensional matrix of 120x40x40 cells (voxel) and a specific vehicle shape are needed (Figure 2).

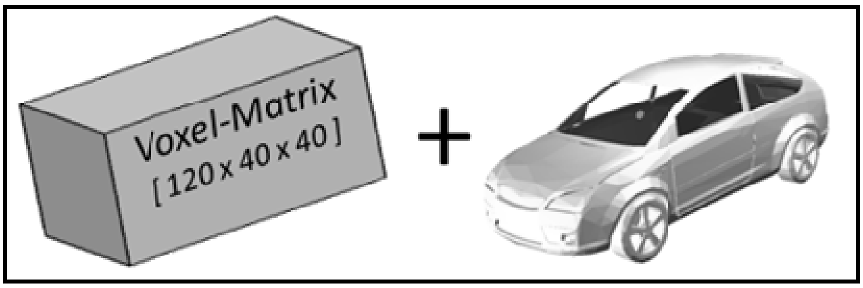

Figure 2. Voxel-Matrix and basic vehicle model

The merging of the vehicle shape and the voxel-matrix to a 3-dimensional vehicle model (Figure 3) concludes this step.

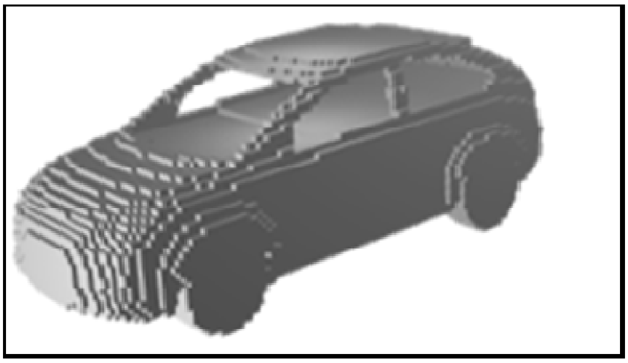

Figure 3. 3-dimensional vehicle model

Currently there are four different car types available (Figure 4):

1. Van
2. Sedan
3. Hatchback
4. Station wagon

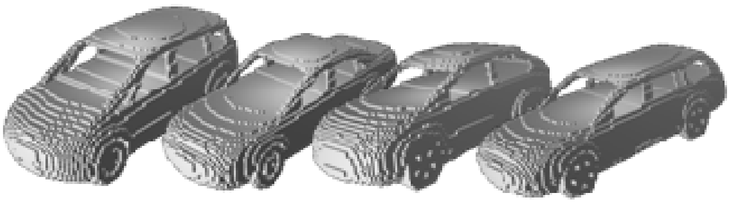

Figure 4. Available car types as voxel models

In the third step the interpolated deformation lines and the 3-dimensional vehicle model are merged to calculate the 3-dimensional vehicle deformation model. An example of such a model is shown in Figure 5. With this the deformed area of the car as well as the deformed voxel of the vehicle model can be identified.

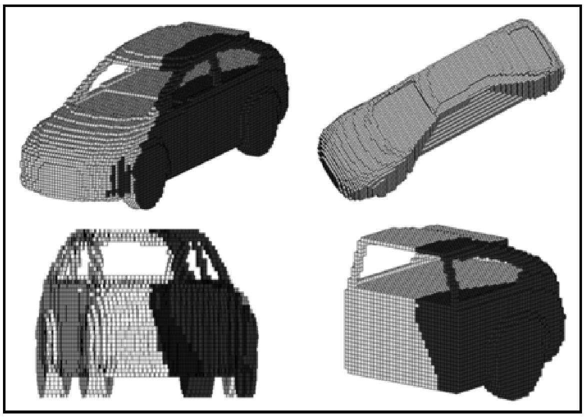

Figure 5. Example of a 3-dimensional vehicle deformation model

In the fourth step the information in regards to the deformation energy during the collision is extracted from the GIDAS database and added to the vehicle deformation model. The deformation energy is coded as a speed value, called EES (energy equivalent speed). Using the vehicle mass (m) it is possible to calculate the kinetic energy before the crash. The deformation energy (E_{ges}) is assumed to be equivalent to the deformation energy.

$$E_{ges} = \frac{m}{2} * EES^2 \quad [1]$$

To distribute the energy among the previously as “deformed” identified voxel and without the knowledge of the actual distribution of material stiffness, certain assumptions have to be made.
The main assumption is that the deformation force increases over the deformation distance until the maximum deformation depth is realized (Figure 6).

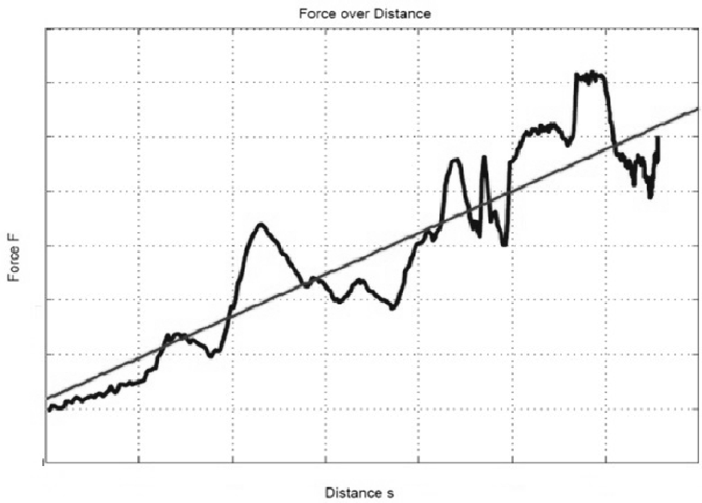

Figure 6. Force over distance (qualitatively)

This conclusion is drawn from the observations made during real world crash tests [2]. Furthermore, if the deformation force is increasing linear, then it integration, the deformation energy, increases quadratic (Figure 7).

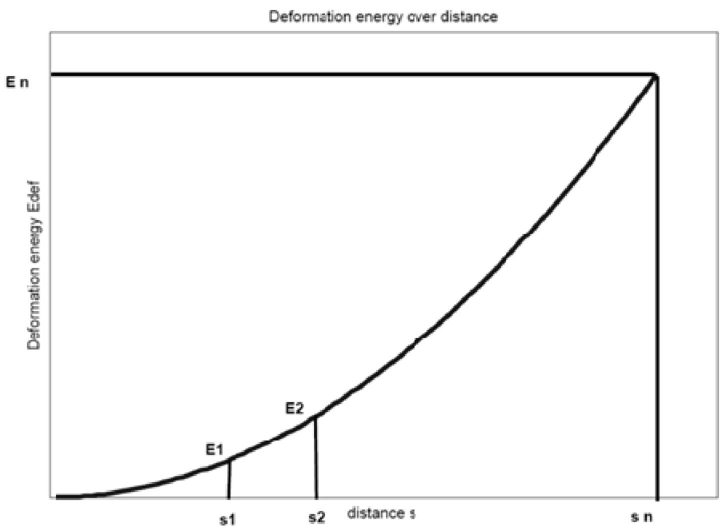

Figure 7. Deformation energy over distance (qualitatively)

Additionally the direction of the impact pulse has to be considered. This information can also be drawn from the GIDAS database and is known as “VDI1”. This parameter is distributed into 12 parts (Figure 8).

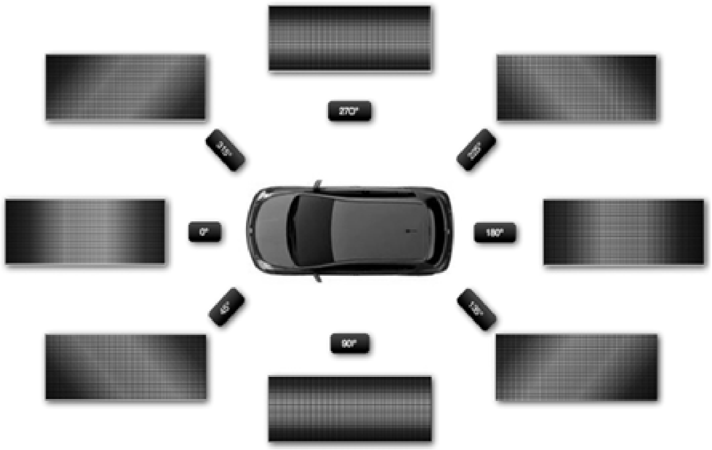

Figure 8. Distribution matrices according to VDI1

Using the direction of the impact pulse and the deformation energy from GIDAS as well as a specific algorithm [2] each voxel of the vehicle deformation model is assigned a specific deformation energy value.
With these steps a 3-dimensional vehicle energy model is created for each car in the database. Now a mean energy value for each voxel and certain car types could be calculated. But due to the variation of cars within the database and therefore also the variation of the level of passive safety (e.g. stiffness of the compartment) a distinction has to be made between:

1. The year of construction
2. The vehicle mass

This leads to the following four groups of vehicle energy models available at the current time for the Automated Crash Computation:

1. Younger, light vehicles
2. Younger, heavy vehicles
3. Older, light vehicles
4. Older, heavy vehicles

The definition of the borders of each group (young/old, light/heavy) can be easily adapted according to its distribution among the cars taken from the GIDAS database [2].

Methodology of the crash computation

The Automated Crash Computation can basically be divided into the following parts:

1. Pre-Process
2. Crash-Simulation
3. Post-Process
4. Assessment

The purpose of the Automated Crash Computation tool is to assess a DAS during its development using real world accident scenarios. Therefore the simulation results, including the new crash constellation (position of the cars) and other relevant parameters (yaw-angle, velocity), are needed as an input for the crash computation.
Furthermore the vehicle energy model is transferred into an EES based model using the mass of each car. If necessary, additional data can be retrieved from databases like GIDAS. The collection of all this data and the preparation for the simulation is done during the pre-process of the tool (Figure 9).

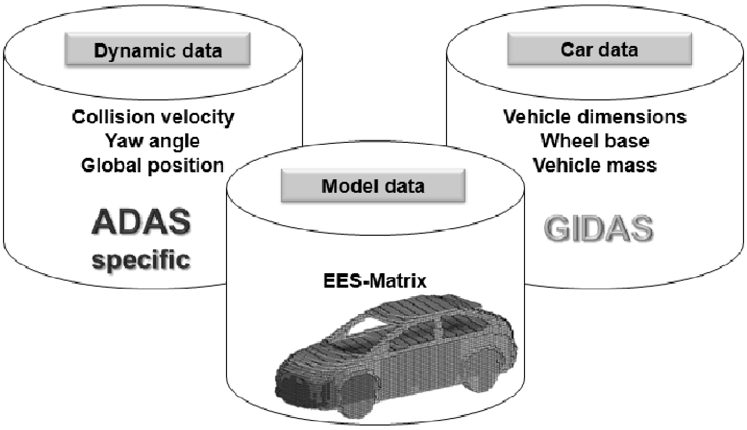

Figure 9. Overview of the pre-process

Then the simulation follows. Within this step the two energy vehicle models are being “crashed” (Figure 10).

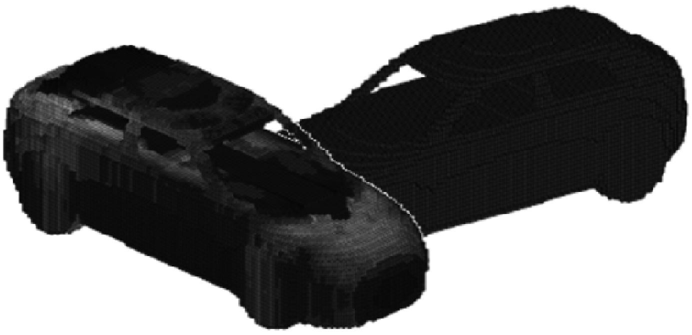

Figure 10. Position of the cars before the crash

In every step of the computation the two vehicle models are driving into one another and the voxels that overlap each other are being compared in regards to their EES-value (Figure 11).

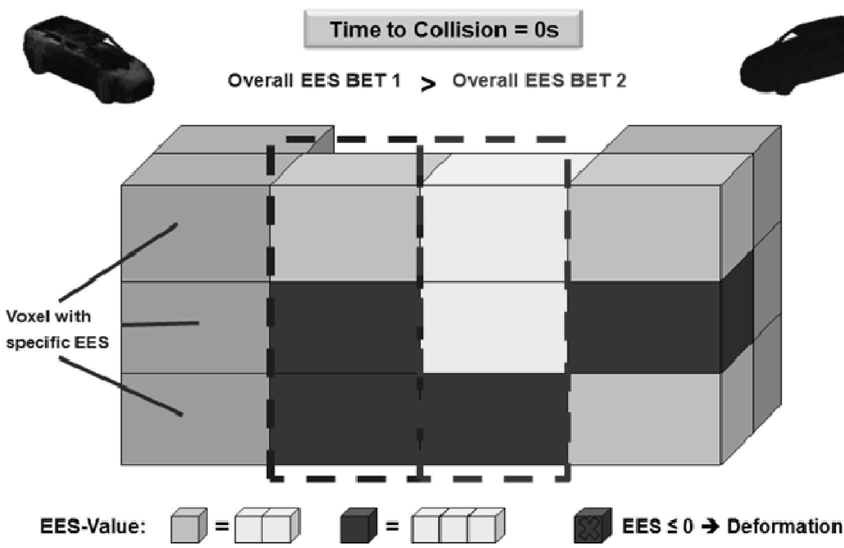

Figure 11. Voxel matrizes before the crash (example)

Then the values are subtracted from one another and if a voxel has a negative EES-value it is deleted from the voxel-matrix of the energy vehicle model (Figure 12).

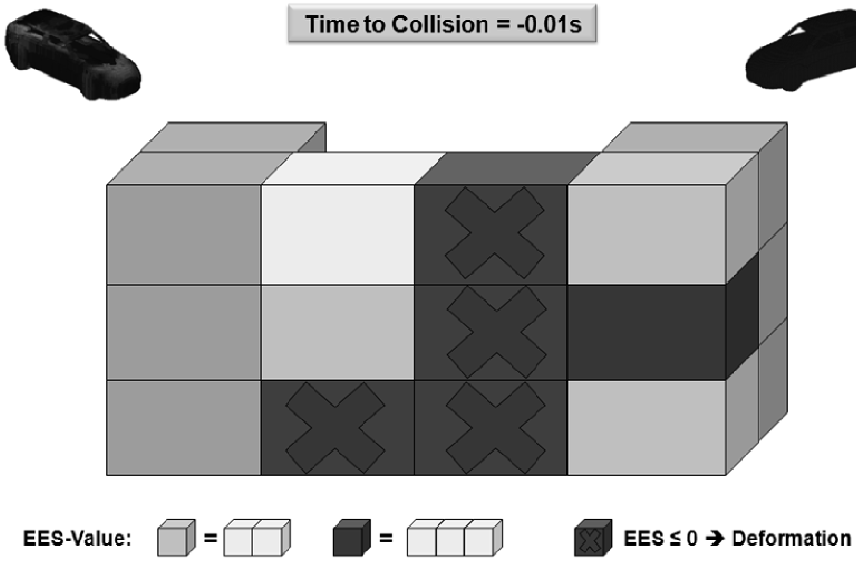

Figure 12. Voxel matrizes after the first computation step (example)

After a specific abortion criterion is reached, the computation is stopped. The resulting deformations of both cars can be seen in Figure 13.

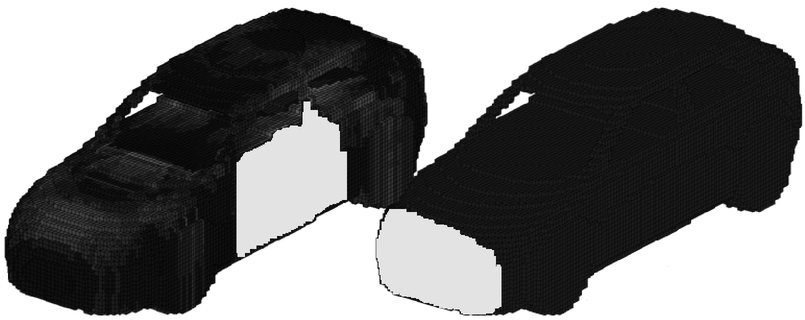

Figure 13. Resulting deformations of the cars (example)

During the post-process further crash parameters (point of impact and impact plane) are being calculated (Figure 14).

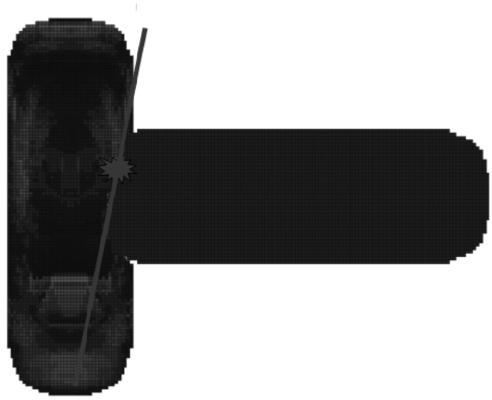

Figure 14. Resulting point of impact and impact plane (Bird's eye view of the crash)

These crash parameters as well as the input data from the simulation of the DAS is handed over to PC-Crash to computate more crash parameters (e.g. delta-v, deformation depth) which is needed to assess the DAS (Figure 15).

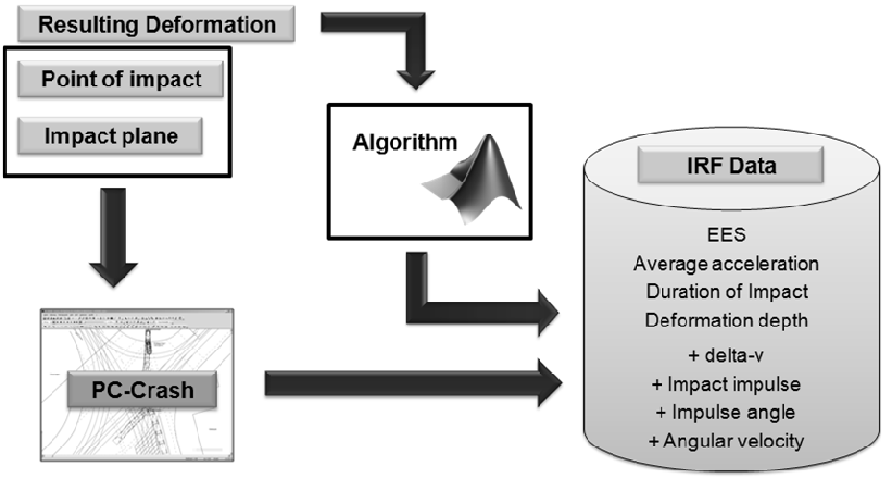

Figure 15. Overview of the Post-Process

Ultimately the data about the crash parameters which was obtained through the automated crash computation will serve as the input data for the assessment of the DAS. For the assessment injury risk functions (IRF) are being used (Figure 16).

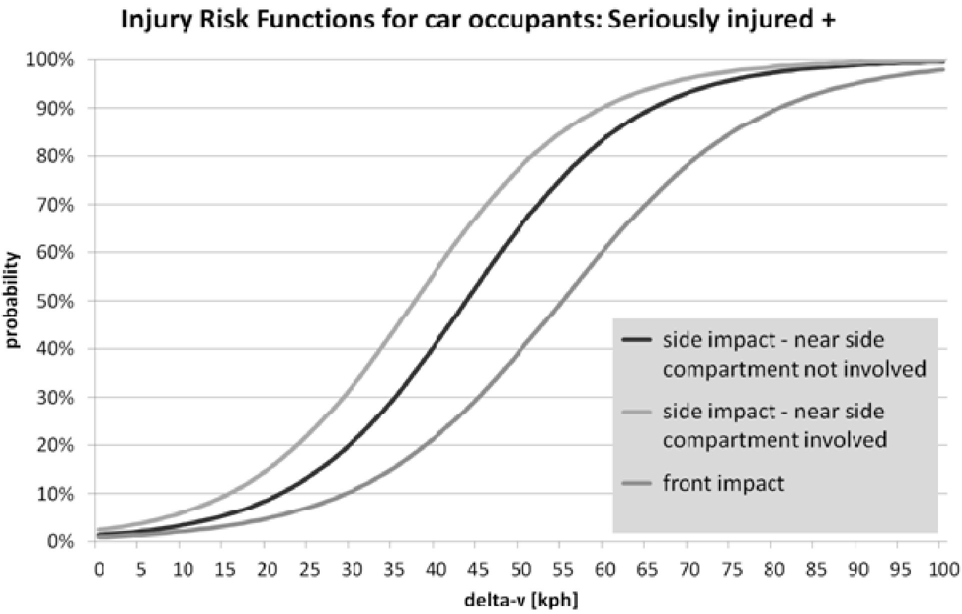

Figure 16. Injury risk functions for the assessment of DAS (example)

These IRF show the probability of different injury severities in relation to different influencing parameters. They can also be obtained from the GIDAS database. More detailed explanations about the IRF can be found in [3].

Application Example

The VUFO was able to test the newly developed tool Automated Crash Computation within the project Ko-KOMP (Cooperating Components). The aim of this project was to examine the effectiveness of different cooperative sensor technology approaches with regard to the degree of protection that could be achieved for the road user [3].
The VUFO supported this project also in terms of assessing the simulated sensor systems (DAS) of the cooperating partners. The basis of the simulation were 35 real world accident scenarios which were extracted from the GIDAS database. From these 35 accidents about 400 virtual accident scenarios were created using a variation of specific driver parameters. An overview of the single project steps is given in Figure 17.

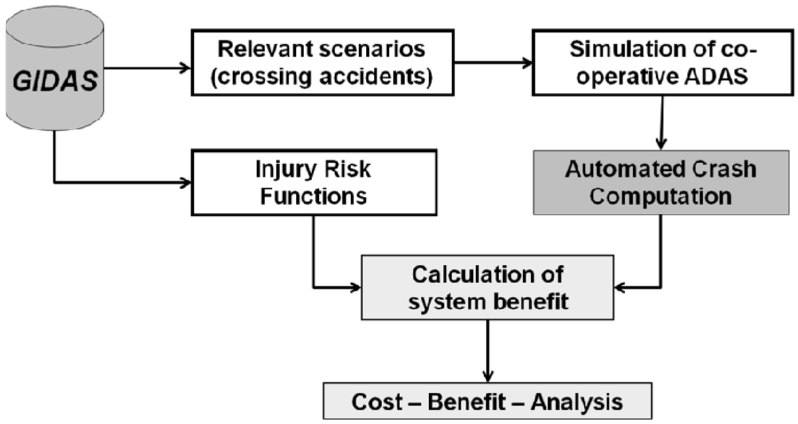

Figure 17. Overview of part of the KoKOMP-Project

By reference to an exemplary case the use of the Automated Crash Computation for the assessment of DAS will be shown hereafter.
As previously stated the tool needs an input in terms of dynamic parameters from the simulation of a specific scenario with and without the DAS. Figure 18 shows the crash constellation of an exemplary scenario without the implementation of a DAS. In this scenario the car on the left is hit on the right side and the compartment is involved.

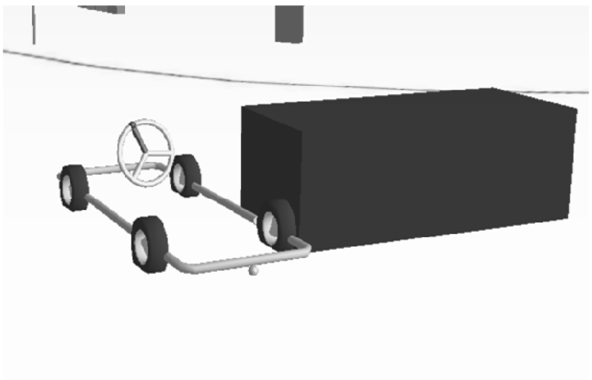

Figure 18. Crash constellation without DAS (front to side, compartment involved)

Figure 19 shows the new crash constellation of the same scenario after a DAS was implemented. Here the car on the left is still hit on the right side. But due to the DAS, which included a braking functionality, this time the compartment is not involved. Additionally the collision velocity, in comparison to the scenario without the DAS, is lower.

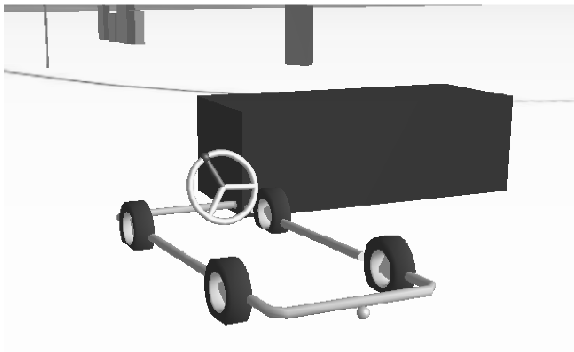

Figure 19. Crash constellation with DAS (front to side, compartment not involved)

Table 1 gives an overview of the crash parameter delta-v of this exemplary case. As it can be seen, through the implementation of the DAS in one car the delta-v of both cars is lowered for about 15kph.

Participant	delta-v w/o DAS [kph]	delta-v w/ DAS [kph]
Left	36	21
Right (block)	40	24

Table 1. Overview of the delta-v (example case)

Now that the crash severity is lowered the IRF can be used to assess the DAS in regards to the decrease of the probability of a certain injury severity.
In Figure 20 this is done for an occupant on the passenger side of the car on the left from the exemplary case. For this person the crash is a near-side collision in both the scenario without and with the implementation the DAS. In this case different injury risk functions were created depending on the side of the impact (front / near side) and on the fact if the compartment was involved or not.

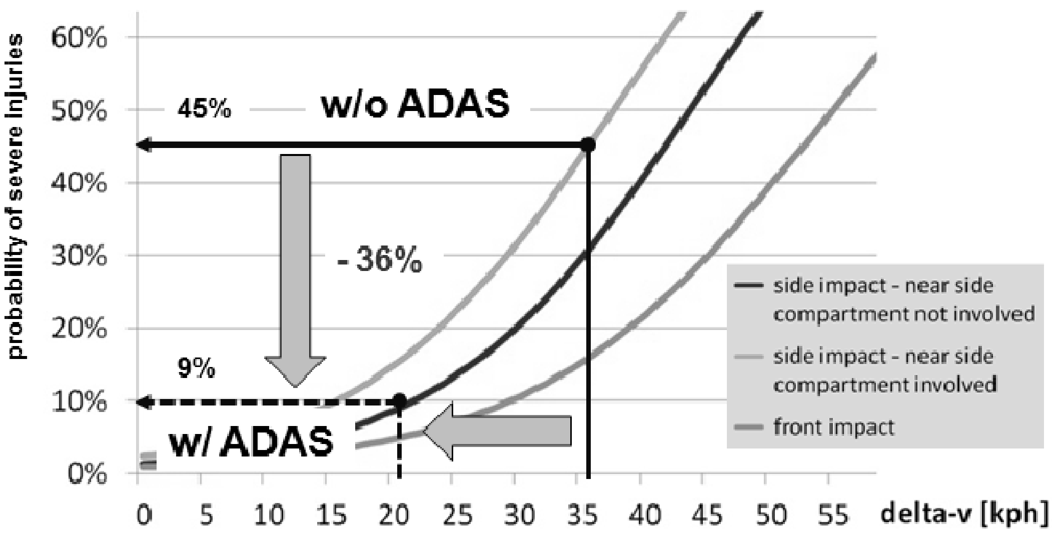

Figure 20. Usage of IRF to assess DAS (example)

For the scenario without the implementation of the DAS the probability to be severely injured for the passenger is about 45%. With a DAS this probability is reduced by about 36% to 9%.
Within the Ko-KOMP project the computation of the crash scenarios as well as the calculation of the probabilities of injury severities using IRF was done for all of the about 400 virtual accident scenarios (with and without DAS).

Summary

The simulation of accidents is a very effective method for both the development and the evaluation of active safety systems. For the evaluation of DAS in regards to their benefit in real-world accidents a crash computation has to be conducted. For this purpose the VUFO has developed an effective tool called Automated Crash Computation. It is based on virtual vehicle models with specific EES-values. These models were obtained from the GIDAS database using vehicle deformations and other parameters. Then an algorithm for the in-crash phase and the energy reduction of the participants was developed and tested.
The feasibility of the Automated Crash Computation tool including the assessment of DAS with IRF was successfully proven for passenger car accidents within the project Ko-KOMP. In this project about 400 virtual accident scenarios with new crash constellations were created from 35 real world

accidents found in the GIDAS database. All of these virtual accident scenarios were then computed and evaluated in regards to the increase of the protection level/ decrease of the injury severity for the car occupants.
Yet, further development of this new method and the tool is needed to attain more realistic results. Additionally the different car shapes available for the crash computation have to be validated and specified in more detail. Furthermore the development of a 3D crash computation is possible and the goal is to implement also the post-crash phase into the tool to be able to compute the crashes without using PC-Crash.

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Accident simulation and reconstruction for enhancing pedestrian safety: issues and challenges

H Hamdane[1,2,3], T Serre[1], R Anderson[2] and J Yerpez[1]

[1] LMA-IFSTTAR, Laboratory of accident mechanism analysis, Salon-de-Provence, France
[2] CASR (Centre for Automotive Safety Research), University of Adelaide Australia
[3] LBA-IFSTTAR, Applied biomechanics laboratory, University of Aix-Marseille, France

Abstract - The enhancement of pedestrian safety represents a major challenge in traffic accidents. This study allows a better understanding of the issues in pedestrian protection. It highlights the potential of in-depth studies in identifying relevant crash parameters interfering in the pedestrian safety. A computational simulation tool was developed to reconstruct pedestrian real-world crashes. A sample of 100 in-depth accident cases was reconstructed from two sources: 40 crashes provided by IFSTTAR-LMA and 60 crashes from CASR. To exemplify the methodology, two accident cases from each database were illustrated.

A description of the sample of crashes was presented including the travel and impact speed of the vehicle, the driver reaction, the pedestrian walking speed, the scene configuration with the eventual obstacles, etc. This detailed description is pointing to the major factors affecting the limits of pedestrian safety systems.

NOTATION

t_0	Beginning of crash sequence (s)
t_{bi}	time at beginning of braking (s)
t_b	time at full braking (s)
t_c	time of collision (s)
T	time interval of the simulation (s)
d	distance from start of skid marks to point of impact (m)
a	Deceleration of the vehicle (m/s²)
V	Speed of the vehicle (m/s)
S	Travel distance of the vehicle (m)
γ	Jerk due to the deceleration (m/s^3)
V_{impact}	Impact speed of the vehicle (m/s)
μ	Coefficient of tire/road friction
g	Acceleration due to gravity (m/s²)
L	Percentage of kinematic energy loss prior to full braking

INTRODUCTION

Each year, more than 270.000 pedestrians are killed on the world's road and millions are non-fatally injured covering a range of severities [1]. Pedestrian safety is a world-wide issue and represents a key challenge to decrease road traffic accidents involving these vulnerable users.

Several studies were performed to enhance pedestrian safety. Accordingly to these studies, measures and interventions have been established encompassing several fields as engineering, enforcement and education. Considerable safety-based technologies have been designed to prevent pedestrian crashes using Intelligent Transportation Systems [2]. These systems allow monitoring in particular the motion of pedestrians (e.g. the European project PUVAME [3], SAVE-U project [4] and WATCH-OVER project [5]). To develop such systems, there is a need to investigate in in-depth crash studies in order to reconstruct crashes and simulate the interaction between pedestrians, vehicles and the road environment.

Researches based on numerical simulation have been explored to assess the performance of safety systems. Some approaches are focusing on identifying typical crash scenarios from in-depth data [6]–[8]. Due to the complexity of driving situations, a considerable number of factors have to be addressed. Rather than synthesizing accidents into common scenarios, other researches were using probabilistic methods like the Monte Carlo method to compute many complex crash configurations [9], [10]. Factors like visibility constraint are not yet covered enough in these methods. So the objective of this research is to reconstruct real accident configuration including factors interfering in pedestrian safety.

This paper presents a method to reconstruct real accidents scenarios using computational simulation. A sample of 100 accident cases involving pedestrians has been reconstructed. To illustrate the method, only two cases were detailed. Finally, the characteristics of the selected crashes were described as fields of interest with respect to pedestrian primary safety.

MATERIALS AND METHODS

This research is based on the reconstruction of 100 real-world crashes involving a pedestrian and vehicle. A computational simulation tool is developed to reproduce the crash sequences displaying the interaction between the vehicle, pedestrian and the crash environment including obstacles. These two steps are described in the following sections.

Accident database

A sample of hundred crashes was provided by two in-depth databases: IFSTTAR-LMA (the laboratory of accident mechanism analysis of the French institute of science and technology for transport, development and networks, France) and CASR (Centre for Automotive Safety Research, University of Adelaide, Australia). Both of these centres proceed in a similar way to perform in-depth investigations as it is respectively described by [11] and [12].

Extensive data are collected from on-scene accidents and are clustered in files as follows:

- Photographs and videos of the crash scene and vehicles involved;
- Statements of people involved in the crash, witnesses, and police;
- Details of the road environment, involved vehicles and pedestrians;
- Details of injuries from medical records;
- A site diagram of the accident drawing to scale including the marks observed on the scene (skid, debris, blood, etc.), the final position of the vehicle and the pedestrian, the estimated impact location and the estimated trajectories of the different subjects involved in the crash.

The hundred cases used for this study were selected corresponding to the available information from the crash database as the estimated impact location drawn on the site diagram of the accident and the assessed impact speed of the vehicle.

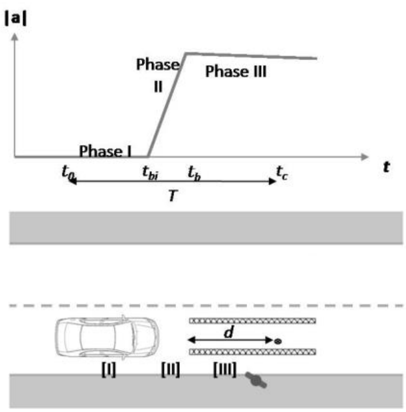
A subset of 40 cases was compiled from the IFSTTAR-LMA crash database. These crashes were investigated around the township of Salon-de-Provence, covering a wide period of 1995-2011. The remaining 60 cases were provided by CASR which investigated in the Adelaide Metropolitan Area in the period April 2002 to October 2005.

Accident modeling

To emulate a crash scenario, required input variables are compiled from the crash databases. These variables are clustered in spreadsheets with accordance to the crash components: the environment, the vehicle and the pedestrian.

The site diagram of the accident is used as a background for the crash simulation. The scale of the diagram expressed in pixel/meter is extracted and saved as a variable. This variable allows getting from the diagram any data with the appropriate dimensions identical to their counterparts in the real world. These data extracted from the diagram are the impact location picked as a reference point, the length of the skid marks – if there is –, and the width of the driving lane from the reference point. Obstacles that may obscure the visibility of the pedestrian are spotted on the diagram. Other data describing the road environment of the crash are extracted from the in-depth database. Some of these data are required for the crash simulation like the tire/road friction coefficient and some are complementary information such as light conditions and traffic flow.

For the vehicle, its dimensions are requested as well as the measured impact location provided by the in-depth database. Using the pre-defined reference point, all these dimensions are set to locate and draw the vehicle on the diagram at the impact. An estimated trajectory is then extracted from the diagram and converted from pixel coordinates (2D) to curvilinear distances or travel distances in meters (1D). These space coordinates are overlapped with the kinematic of the vehicle computed through the equations of motion. These equations are associated to the pre-crash sequence depending on whether the driver did brake or not (Figure 1). For cases with no braking maneuver, the vehicle is assumed to drive under a constant speed (the impact speed) described by Equation 1. For cases where the brakes are triggered, the vehicle goes through different motions: a motion presumed to have a constant speed, a transition phase and a uniform deceleration (Figure 1). Each phase is represented by the appropriate equation of motion (Equation 1-9). The parameters of these equations are retrieved from the estimated impact speed of the vehicle, the length of the skid marks, the time for the braking system to lock the wheels and time interval of the simulation. The time to lock the wheels is the time elapsed for the vehicle to travel from the application of the brakes to the wheels locking and producing visible skid marks. This time interval depends on the braking system of the vehicle: for Brake Assistant Systems or equivalent, this time characteristic is assumed to be 0.2secs, and for normal brakes, it is 0.5secs as defined by [13]. During this time interval, there is a loss of kinetic energy of 80%. The sequences of the vehicle motion are finally modeled in a spatiotemporal continuum.



Phase I ($t \leq t_{bi}$)	Phase II ($t_{bi} \leq t \leq t_b$)	Phase III ($t_b \leq t \leq t_c$)
$S(t) = v_I \times t + s_I$ [1] $V(t) = V(t = t_{bi})$ [2] $a(t) = 0$ [3]	$S(t) = \frac{1}{6}\gamma_{II} \times t^3 + \frac{1}{2}a_{II} \times t^2 + v_{II} \times t + s_{II}$ [4] $V(t) = \frac{1}{2}\gamma_{II} \times t^2 + a_{II} \times t + v_{II}$ [5] $a(t) = \gamma_{II} \times t + a_{II}$ [6]	$S(t) = \frac{1}{2}a_{III} \times t^2 + v_{III} \times t + s_{III}$ [7] $V(t) = a_{III} \times t + v_{III}$ [8] $a(t) = \mu g$ [9]
À $t = t_0 = 0$, $\begin{cases} V(t_0) = V(t = t_{bi}) \\ S(t_0) = 0 \end{cases}$	À $t = t_b$, $t_b = T - \frac{-V_{impact} + \sqrt{V_{impact}^2 + 2\mu.g.d}}{\mu g}$ $\begin{cases} V(t = t_b) = \sqrt{V_{impact}^2 + 2\mu.g.d} \\ a(t = t_b) = \mu.g \end{cases}$ À $t = t_{bi} = T - t_b - 0.5$, $\begin{cases} V(t = t_{bi}) = \frac{V(t = t_b)}{\sqrt{1 - L}} \\ a(t = t_{bi}) = 0 \end{cases}$	À $t = t_c = T$, $V(t_c) = V_{impact}$

Figure 1. Brake model for the crash reconstruction

For the pedestrian, the trajectory is also extracted from the site diagram. Its kinematic is assumed to be at constant velocity. Since it is missing in in-depth databases, the speed of pedestrians is estimated based on the work of [14]. This speed is the mean of the normal speed distribution related to the pace and age of the pedestrians (Table 1). At the end, the trajectory is combined to the kinematic parameters to locate in space and time the pedestrian all along the accident scenario.

Table 1
Pedestrian speed estimation

Age	50% speed (m/s)	
	Walking	Running
5-9	1.83	3.94
10-14	1.68	4.20
15-19	1.65	4.20
20-29	1.62	3.54
30-39	1.62	3.35
40-44	1.62	2.90
45-49	1.52	2.90
50-54	1.52	2.83
55-59	1.46	2.83
60-64	1.46	2.47
65+	1.28	2.47

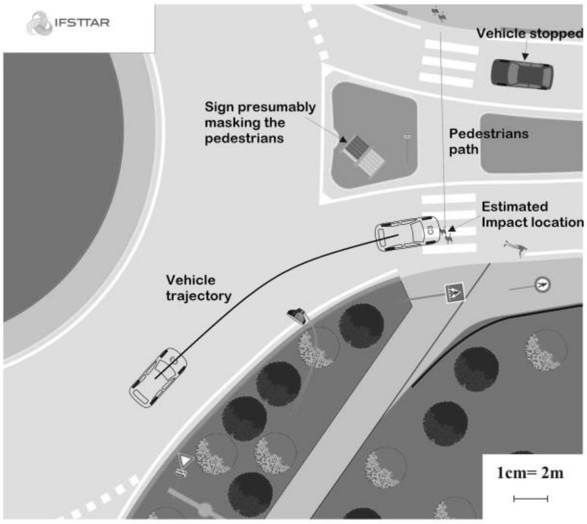
RESULTS

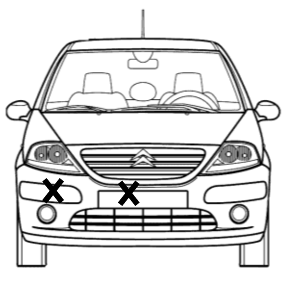
Examples of accident reconstruction

The method of accident reconstruction is illustrated here by two cases: one case from IFSTTAR-LMA database and another from CASR.

Example 1

On a rainy day in the morning, a 2004 MY Citroen C3 took the first exit at a roundabout. In the middle of the lane, the vehicle struck two kids on a pedestrian crossing. The 6 and 10 years old boys were holding their hands while running to cross the road. After a vehicle stopped to give them way to cross, the pedestrians run across the road without paying attention to the oncoming vehicles. Although there was a pavement separating the lanes, the visibility of the pedestrians was masked by a sign of 2.4m wide but with low height. The driver of the Citroen C3 declared that he didn't see the kids crossing due to the heavy rain. The youngest child was struck approximately in the center of the vehicle and has been forwarded straight ahead, while the other child was hit by the right front edge of the vehicle and thrown on the right side of the road. The driver did not stop the vehicle and continued his itinerary as he didn't notice that a collision occurred (according to the driver's statement).
The 10 years old boy was not injured. Concerning the other kid, after been thrown straight forward to the vehicle path, he found himself trapped underneath the vehicle and carried for approximately 1km. He suffered from multiple lacerations. He has been transferred to the hospital.
The driver did not react. There was no evidence of pre-impact or post-impact braking, so the travelling speed and impact speed of the vehicle has been considered as the same. This speed was assessed at 25 km/h from the thrown distance of the pedestrian estimated at 4m. This speed was also consistent with the measured speed of the vehicles driving through that section of the road.





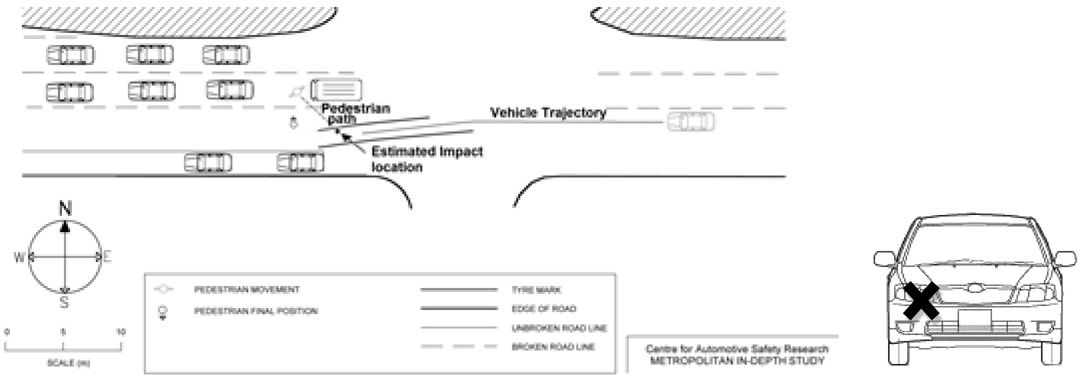
Environment	Vehicle	Pedestrians
Impact location estimated at the middle of the walkway; No skid marks *Infrastructure* lane width from impact: 2.75m One driving lane; Urban area Speed limit: 50km/h *Masking obstacles* Type: sign Width: 2.4m Height: 0.5m Distance obstacle/vehicle side: 2.9m *Weather and light conditions* Day time Heavy rain Wet road : tire/road friction coefficient of 0.6	C3 Citroen (2004 MY): B-segment or subcompact hatchback *Dimensions* Length: 3.85m Width: 1.66m Distance Gravity Center /front-end of the vehicle: 1.85m Action: turning right (first exit of a roundabout) No emergency maneuver Estimated travel/impact speed : 25km/h First impact on the vehicle Distance from the center : 0m	2 kids: 6 and 10 years old Struck on their right side Action: crossing on a walkway without looking at the oncoming vehicles Pace: running Estimated speed : 14 km/h Pedestrian 1 (6 years old) Impact: center of the vehicle Projection: forward trajectory Severe injuries, MAIS: 3 Pedestrian 2 (10 years old) Impact: right front-end corner Projection: thrown off to the right-hand side Minor injuries
Vehicle turning; Masked pedestrians; Inclement weather; Frontal impact; No deaths, MAIS : 3		

Figure 2. Example case 1

Example 2

On a clear day, a Toyota Corolla® (Sedan MY2002) was heading west in left lane of a 3 lane highway. A 58 years old pedestrian was crossing (jaywalking) the highway, walking between vehicles stopped due to traffic. The driver of the Toyota saw the pedestrian previously masked by a stationary van type vehicle, and then applied the brakes locking them up. Unfortunately, the crash happened even if the vehicle swerves to the left. The pedestrian struck with the right front of the vehicle.

The pedestrian was admitted to the hospital for 2 days. A laceration and hematoma to the occipital region of the scalp, a comminuted fracture of the right clavicle with contusion and a fracture to the right fibula head/neck were recorded.
From the skid marks left on the dry road (9.6 and 13.28m long), the traveling speed of the vehicle was estimated at 55 km/h. The impact point was assessed based on a compromise between the results of the impact speed from the formula of Searle and Searle (1983) and the equation of a uniform deceleration. Hence, the post impact skid marks was evaluated at 2.25m, the throw distance of the pedestrian was about 3.2m and the impact speed was estimated at 20 km/h.



Environment	Vehicle	Pedestrians
skid marks: 9.6 and 13.28m pre-impact skid: 11m *Infrastructure* lane width : 2.5m driving lanes: 3 Traffic flow: busy *Masking obstacles* A van Distance obstacle/vehicle side: 1.8m *Weather and light conditions* Day time Dry weather Dry road : tire/road friction coefficient of 0.72	Toyota Corolla (2002 MY): B-segment or subcompact sedan *Dimensions* Length: 4.18m Width: 1.71m Distance Gravity Center/front-end of the vehicle: 2.1m Action: driving straight Emergency maneuver: Braking and steering Estimated impact speed : 20km/h Estimated travel speed: 55km/h First impact on the vehicle Distance from the center : 0.7m	male: 58 years old struck on the left side Action: crossing through stationary traffic Pace: walking Estimated speed : 5.2km/h *Injuries* head: laceration + hematoma thorax: right clavicle fracture lower leg: fibular head fracture 2 days hospital No death MAIS: 2
Masked pedestrian; Impact with the right-front of the vehicle ; No deaths, MAIS : 2		

Figure 3. Example case 2

Description of the crash set

During the process of crash reconstruction, a set of data was constituted. An analysis of this data is presented in this section and clustered with accordance to the different components of a crash: The road environment, the driver, the vehicle and the pedestrian.

Road environment

The majority of the accident cases happened during the day (83%). Among these cases, inclement weather and bad light conditions are observed: heavy rain (4%) and dazzling light (7%).
The road curvature is also considered in this analysis. There are 18% of cases where the vehicles involved in the crashes were turning.
Finally, there is a major concern in this set about obstacles. In 22% of cases, pedestrians were masked by obstacles which are mainly parked vehicles or stopped due to traffic (Figure 4). In 80% of cases where the pedestrians are masked, the lateral distance between vehicles involved in crashes and obstacles is above 1m (Figure 5). All the pedestrians are visible (there is no more obstacle) when they are located at half a meter from the side of the vehicles.

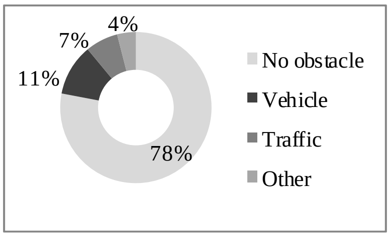


Figure 4. Rates of masked pedestrians by obstacles

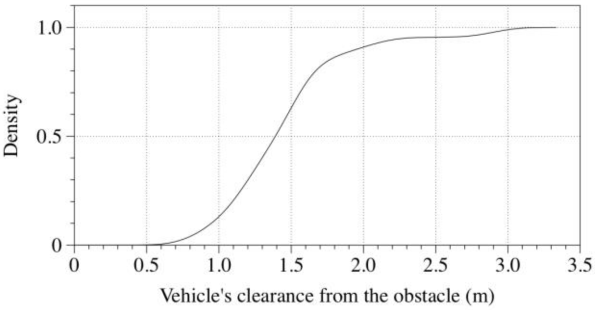


Figure 5. Cumulative distribution function
of the vehicle's clearance from obstacles

Driver reaction

The driver's reaction according to the crash sequences is described. The different emergency maneuvers applied by the driver are rated in Figure 6. This chart brings out two main groups: cases "with braking maneuvers" representing 33% of the dataset and cases "without braking".

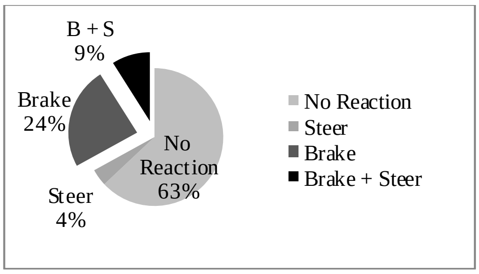


Figure 6. Emergency manoeuvre distribution

Vehicle speed distribution

The interesting parameters relative to the vehicle involved in the crash are the travel speed and the impact speed. Figure 7 shows the distribution of both speeds through the whole set of crashes. 95% of the vehicle travel speeds are distributed along a wide range from 20 to 60 km/h, with a peak around 40 km/h, while the average vehicle impact speed is 32 km/h.

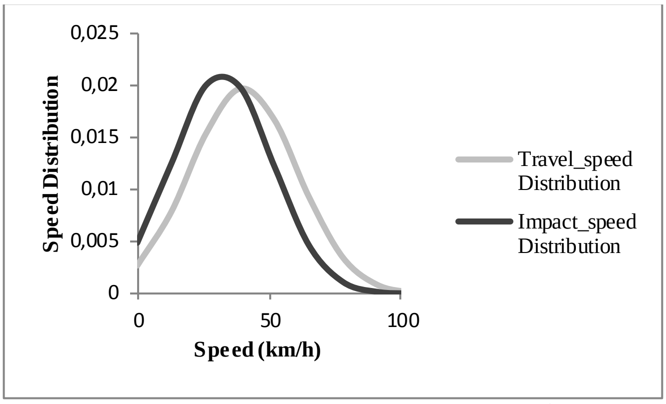


Figure 7. Travel and impact speed distribution of the vehicle

Pedestrian pace

Two different distributions are displayed corresponding to the pace of the pedestrian (Figure 8). In fact, there are 25% of cases where the pedestrian is running with an average speed of 3.5m/s (~12.6km/h). For walking pedestrians, their average speed is 1.4m/s (~ 5km/h).

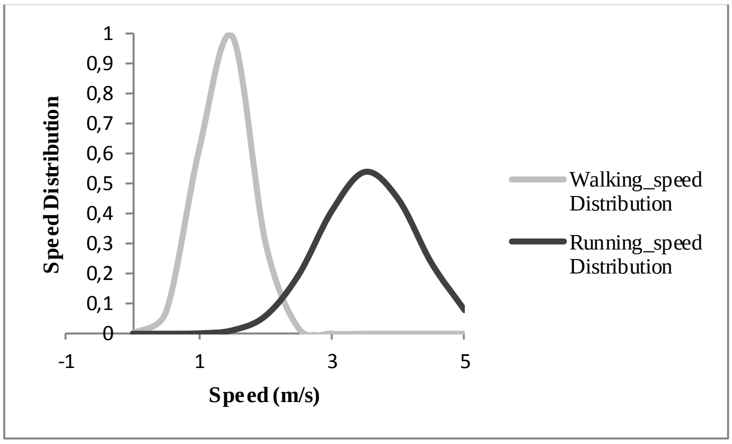


Figure 8. Pedestrian speed distribution according to the pace

Crash Configuration

The crash configuration analysis combines the trajectory of the pedestrian with the impact location on the vehicle according to the timeline of the crash. The objective is on one hand to determine if the collision of the pedestrian happened at the beginning, mid or end of his crossing, and on the other hand to identify if the pedestrian was coming straight from the curb or already crossing from off-side the road (Figure 9). 6 scenarios are established from these combinations. There are as many cases of pedestrians coming from the near side (the curb) as those crossing a lane. The remaining 2% are static pedestrians. The most occurred scenario representing a quarter of the sample is pedestrian struck straight away after stepping from the curb.

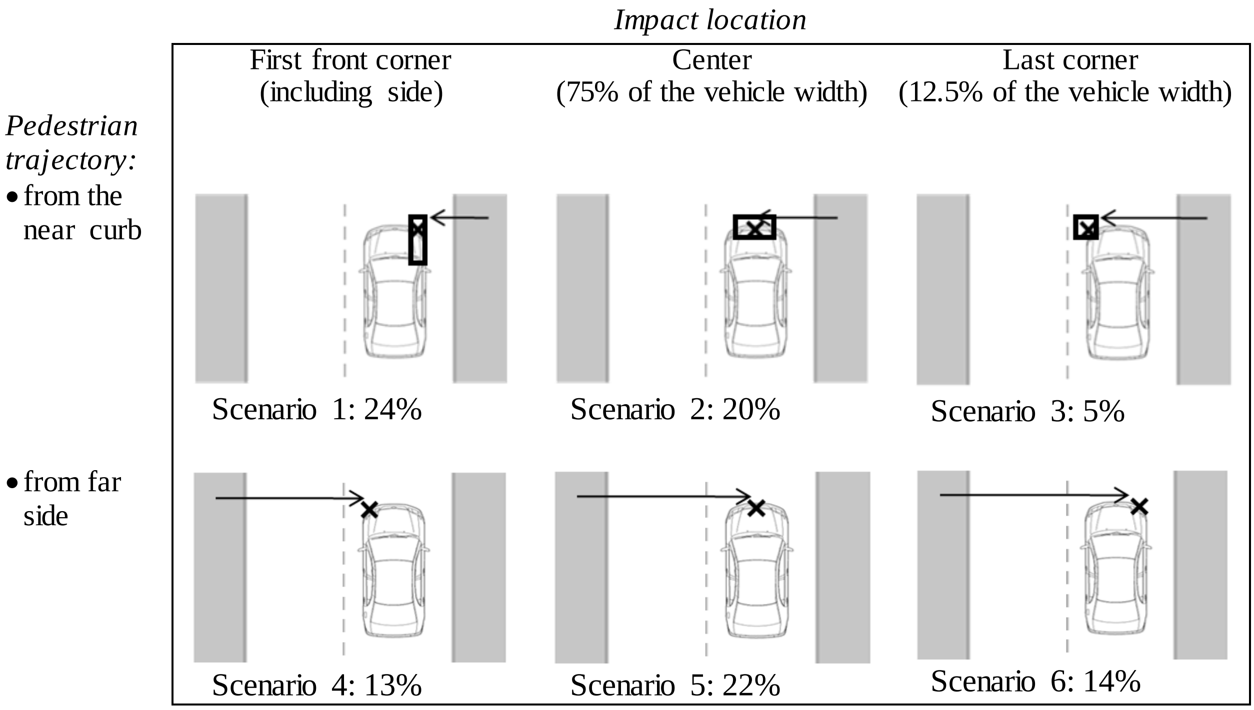


Figure 9. Description of the configuration of the crash dataset

DISCUSSION

Detailed in-depth investigation and reconstruction of crashes involving pedestrians is required as data sources to understand issues in pedestrian active safety. Considering real accident scenarios, it allows identifying factors that interfere in pedestrian safety. These factors are related to the components that model a crash scenario: the road environment, the driver, the vehicle and the pedestrian.

The road environment factors are considered as influencing in the perception of pedestrians. Systems based on sensors that monitor the road to detect any pedestrian are subjected to these factors. Despite their performance, sensors are affected by light and weather conditions such as night time or heavy rain and dazzling light. These constraining conditions cannot be modeled in the simulation of crashes. Yet, researchers working within the ASPECSS project are trying to perform lab test in night conditions [15].
Furthermore, it is presumably challenging for on-board systems to detect a pedestrian while the vehicle is turning.
In the literature, the most studied factor from the road environment factors consists of the impact of road side obstacles in hazard perception [16]. In fact, this factor leads to a late detection of the pedestrian and thus, constrains the safety system to react in limited time and space. It is then important to consider this factor particularly since it is not complicated to model it in the crash simulation. These obstacles can be differentiate and classified into different crash scenarios as described by Brenac et al. [17].

Other factors from the road environment have also an influence in the situation analysis and decision making relative to active safety systems fitted in vehicles. These systems employ emergency braking and some may possibly employ emergency steering as a countermeasure to avoid an imminent crash [18]. Braking as well as steering depends on the road state expressed through the tire/road friction model. Moreover, steering maneuver is restricted by a considerable number of additional factors such as the traffic situation and it is parameterized according to the road boundaries (road width) and other features related to the vehicle.

Regarding the driver, information on emergency situation control before impact is relevant to the effectiveness of safety systems. In 63% of the studied cases, the driver did not react before the collision occurs. It is then interesting to understand the driver alertness and to justify the use of warning systems. On another hand, driver's behavior can annihilate the deployment of an autonomous steering system. So, active systems have to consider the attitude of the driver in emergency driving situation.

When referring to vehicle factors, the speed is the most studied in assessing risk. It is an important parameter interfering in the situation analysis and crash prediction. 95% of the travel speed of vehicles involved in pedestrian crashes range up to 60 km/h. Although the studied crashes are from two different sources (Australian and French crash databases), the speed distribution remains the same and it is similar to the survey of the GIDAS database [15]. Other factors from the vehicle are not covered in this study but are relevant in particular for parameterize steering maneuver. These factors are the lateral acceleration, steering angle and yaw rate.

Concerning the pedestrian, the most influential factor is the walking speed. As the vehicle speed, this factor is also considered in the process of situation analysis and crash prediction. In the crash database developed in this study, most of the pedestrians were walking normally (75%) with an average speed of 5 km/h. This walking speed is comparable to those found in literature [19]. However, the average speed of pedestrians who were running is higher than expected (12.6 km/h).

Considering the trajectory of the pedestrian and the impact location on the vehicle, the performance of active systems may be affected. For example, under certain circumstances, steering maneuver can be appropriate to avoid a particular crash configuration: a pedestrian coming from the curb and striking the nearest front corner or the side of the vehicle. Braking maneuver in this case is limited due to a late detection of the pedestrian leading to a short time available for deployment. This crash scenario is frequently repeated representing 24% of the whole set of studied crashes in this research. This scenario is also significant according to the GIDAS database [10]. The potential performance of steering maneuver as countermeasure in crash avoidance is thus more favorable than braking in particular crash scenarios.

Concerning the crash reconstruction, detailed information are required like the impact location, the trajectories and velocities of the parts involved in the collision, the vehicle features and the location of eventual obstacles that masks the visibility of the pedestrian. All of the crashes reconstructed in this study were selected according to the availability of most of the required data aforementioned. Some data remains missing such as pedestrian speed and some are fuzzy like the approach speed of the vehicle during the pre-crash events. It is clear that assumptions are needed to complete the reconstruction of a crash. Extensive work is necessary to fill these gaps. The use of Event Data Recorder with or without video sensors provides promising data to study pre-crash scenarios [20].

CONCLUSION

The enhancement of pedestrian safety represents a major challenge in traffic accidents. It appears important to pursue in-depth studies of crashes involving pedestrians. These studies allow a better understanding of the issues in pedestrian protection.
A computational simulation tool was developed to reconstruct 100 real-world crashes involving vehicles and pedestrians. The simulation tool reproduces the crash sequences displaying the interaction between the four components: driver, vehicle, pedestrian and the environment including obstacles. The objective of the crash reconstruction was to provide a comprehensive set of data describing the crash sequences.
These detailed descriptions are pointing to the major issues concerning the development of Active Safety System and also identify their limits. In particular, it appeared important to take into consideration the speed of the pedestrian, its trajectory, the obstacles, the driver reactions, etc.

With the designed tool for computational simulation, it is possible to implement active systems like Autonomous Emergency Braking systems in order to assess their safety benefits. It is one of the next steps of this research: to evaluate AEB or ADAS using this accident database.

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UR:BAN KA-WER: Accident Data Analysis and Pre-Crash Simulation for the Configuration and Assessment of Driver Assistance Systems in Urban Scenarios

V Labenski*, J Dobberstein** and T Schlender***

*Group Research, Volkswagen AG, 38436 Wolfsburg, DE
**Automotive Safety, Federal Highway Research Institute (BASt), Brüderstr. 53, 51427 Bergisch Gladbach, DE
***Robert Bosch GmbH, 71701 Schwieberdingen, DE

Abstract - The project UR:BAN “Cognitive assistance (KA)” aims at developing future assistance systems providing improved performance in complex city traffic. New state-of-the-art panoramic sensor technologies now allow comprehensive monitoring and evaluation of the vehicle environment. In order to improve protection of vulnerable road users such as pedestrians and cyclists, a particular objective of UR:BAN is the evaluation and prediction of their behaviour and actions. The objective of subproject “WER” is development support by providing quantitative estimates of traffic collisions at the very start and predict potential in terms of optimized accident avoidance and reduction of injury severity. For this purpose an integrated computer simulation toolkit is being devised based on real world accidents (GIDAS as well as video documented accidents), allowing the prediction of potential effectiveness and future benefit of assistance systems in this accident scenario. Subsequently, this toolkit may be used for optimizing the design of implemented assistance systems for improved effectiveness.

INTRODUCTION

BMWi-funded research project UR:BAN

Accidents in urban areas differ from the ones occurring on rural roads or freeways, their relative importance increasing with overall fatality numbers declining. This is due to the higher share of vulnerable road users involved in urban accidents (see fig. 1). Hazardous situations in urban areas pose particularly tough challenges for active driver assistance systems: Space confinement due to buildings close to roadsides and infrastructure elements, the relevant traffic situations are usually complex due to the high density of road users.

The objective of UR:BAN is to develop active driver assistance technologies for urban accident scenarios and the reduction of the number of injured road users in urban traffic. 31 partners including automobile and electronics manufacturers, suppliers, communication technology and software companies, as well as research institutes and cities have joined the cooperative project UR:BAN in order to develop advanced driver assistance and traffic management systems for cities. The focus is on human factors in all aspects of mobility and traffic. Research objectives are pursued in three main target areas: Cognitive Assistance (KA), Networked Traffic System (VV) and Human Factors in Traffic (MV).

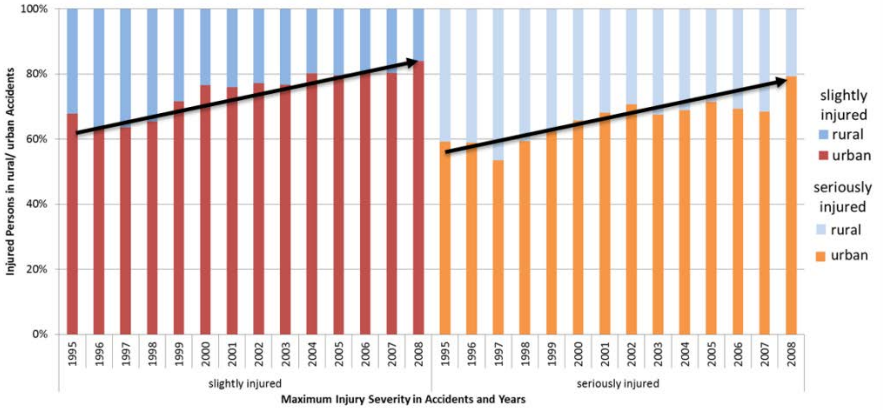

Figure 1: Trends in maximum injury severity in urban traffic accidents [GIDAS]

In UR:BAN KA, there are three subprojects addressing sensor requirements for the detection of various road user groups and assistance strategies. The project “Protection of Vulnerable Road Users (SVT)” further develops enhanced detection systems in order to avoid collisions involving pedestrians and cyclists. The project “Collision Avoidance by Swerving and Braking (KAB)” analyses optimized accident avoidance strategies for urban conflict situations such as accidents at intersections. In “Safe Lateral and Longitudinal Vehicle Control in Cities (SQL)”, technologies designed for continuous support in longitudinal and lateral control e. g. on freeways are modified in order to facilitate acquisition and control tasks in demanding urban scenarios such as bottlenecks caused by parked cars as well. The cross-sectional subproject “Target Population, Effectiveness, and Law (WER)” supports the three application-based projects by assessment of accident avoidance potentials, effectiveness evaluation by virtual accident simulation and legal evaluation.

ACCIDENT DATA

GIDAS database

The major objective in assessing accident avoidance potentials is a precise assessment as to the positive potential of a driver assistance technology on accident scenarios in urban areas. This assessment requires accident data containing relevant accident parameters in order to determine the influence of functional limits (weather, road layout). Official police recorded accident statistics do not cover aspects such as collision speed or pre-crash trajectory, hence the accident data are limited and will not allow statistical traffic accident overviews. GIDAS (German In-Depth Accident Study) was established in 1999 as a cooperation project between the Federal Highway Research Institute Germany (BASt) and the research association on automotive engineering of German Car Industry (FAT). In-depth data in GIDAS combines data collection at the accident scene and the time of the accident applying retrospective methods like measuring, collection of medical data and accident reconstruction. The general concept of GIDAS is to compile a random, un-biased and representative sample of 2,000 accidents involving injury per year to cover all parameters of German road accident scenarios. No pre-selection of severe cases is performed, but all accidents involving injuries as defined by the police are considered. The accident reconstruction is conducted for each GIDAS case, a unique feature of GIDAS, since information for accidents of all severity classes [5] is available. The project UR:BAN focuses on the pre-crash matrices describing trajectories and kinematics of involved vehicles and pedestrians and therefore allow using reconstruction information of real accidents for the virtual simulation of driver assistance technologies during the development of these features.

KOTI data Video-recorded accidents

A further accident data source is a sample of 4,000 video documented accidents of Korean taxis in the region of Seoul [4]. Dash-board cameras are installed for legal reasons in taxis which record taxi driver trips and are triggered by events such as acceleration peaks. The data base covers all aspects of Korean urban traffic. These accident videos were analyzed to determine vehicle and opponent trajectories and link it with overall accident data such as type, site, weather and speed. Main advantages of this source are insights in real interactions, the pre-crash phase and triggering revealing whether or not e. g. pedestrians were aware of the approaching vehicle. This information is crucial for the development of active driver assistance technologies. The effectiveness assessment in UR:BAN can be amended by these insights, nevertheless at first differences between GIDAS data and KOTI data have to be determined.

Official German national accident statistics

BASt has access to the official German national accident data for scientific purposes allowing the analysis of all police reported accidents involving injuries in more detail than based on published accident statistics tables [6]. Full accident statistics ensure the linking of accident statistics with make and model of involved vehicles and analyze the effectiveness of safety devices. For UR:BAN, there are two applications for the use of national accident data: first, the number of accidents and involved injured persons of 2012 are used to extrapolate from GIDAS to the German accident numbers. Second, for SVT, these data may be compared to accident analyses with pedestrians and cyclists involved, since relevant scenarios are defined based on the 3-digit GDV accident type available in both GIDAS and 42 % of German national accident data.

ASSESSMENT METHODOLOGY IN UR:BAN KA-WER

Target population and effectiveness

The estimation of the target population and the evaluation of effectiveness are main tasks of the UR:BAN subproject Target Population, Effectiveness, Law. As shown in fig. 2, the effectiveness of a system is assessed in a two-stage process.

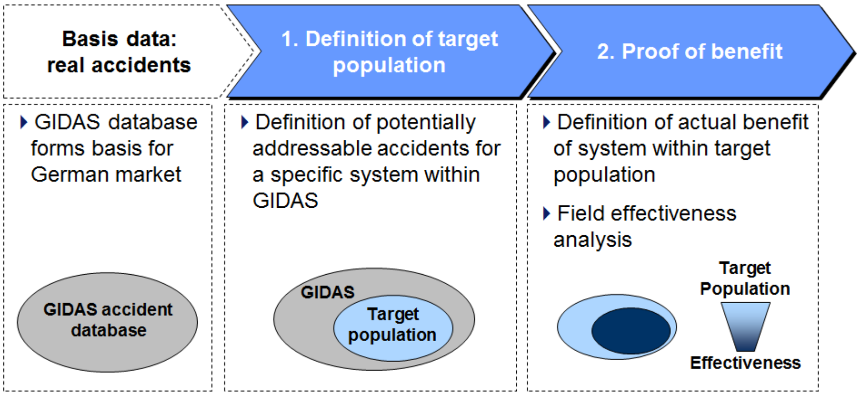

Figure 2: Two-stage process for verifying effectiveness

First, the target population of the system, i.e. all potentially addressable accidents need to be defined on the basis of the accident database. A precondition is detailed knowledge of these incidents. Not only the collisions themselves and their effects are crucial, but also in particular comprehensive information about the pre-crash phases, because active safety and driver assistance systems already engage during these periods. An optimal basis is a numerical description of the pre-crash phase based on accident reconstructions. The corresponding data for Germany are available in the GIDAS database (German In-Depth Accident Study, [3]) (compare paragraph ACCIDENT DATA)
The target population thus defined also sets the upper limit for the effectiveness of the system, corresponding to the effectiveness of optimized safety and driver assistance systems that could prevent accidents addressed by the systems. In reality, the benefit of a system will always be below this limit. The task of the software-based benefit assessment is to determine this percentage precisely. While the target population can still be determined via a selective database query, a temporally and geometrically exact simulation of the accidents is indispensable for determining the benefit of the system.

The goal of the virtual benefit assessment is to predict the effectiveness of safety and driver assistance systems for the overall incidence of German accidents, therefore, the data pool, which merely considers a subset of this total, must be projected. This step also considers a second aspect: Although GIDAS is approx. representative of traffic accidents in Germany (with the existing data acquisition scheme), deviations from the German Federal statistics [6] exist, which can be corrected by a method of extrapolation (compare paragraph PROJECTION).

The entire process of assessment within the subproject is illustrated in fig. 3. The starting point is the German accident situation, available from a representative random sample in the form of GIDAS PreCrash matrices (see [2]).

The next step defines, as described above, the target population of the system to be assessed. This also applies to selecting cases for the accidents to be simulated. The next step simulates the selected cases within the software. The accident reconstruction software PC-Crash forms the core of the simulation of the driving dynamics and the environment. The result of this simulation are modified technical collision parameters, such as Δv (change in speed due to the collision), the angle of collision and the point of contact for the individual accidents.

For converting the technical accident severity (represented by the result of the simulation in PC-Crash) into injury risks for the persons involved, injury risk functions are employed. These functions represent the risk of suffering an injury of the given severity as a function of technical parameters. For effectiveness assessment all persons involved in the particular accident are considered and each individual injury risk is evaluated. When all simulated accidents are taken into account the overall effectiveness of the system results. It is the reduced overall injury risk represented by vehicles with assistance systems is used to evaluate the effectiveness compared to the overall injury risk represented by cars without system.

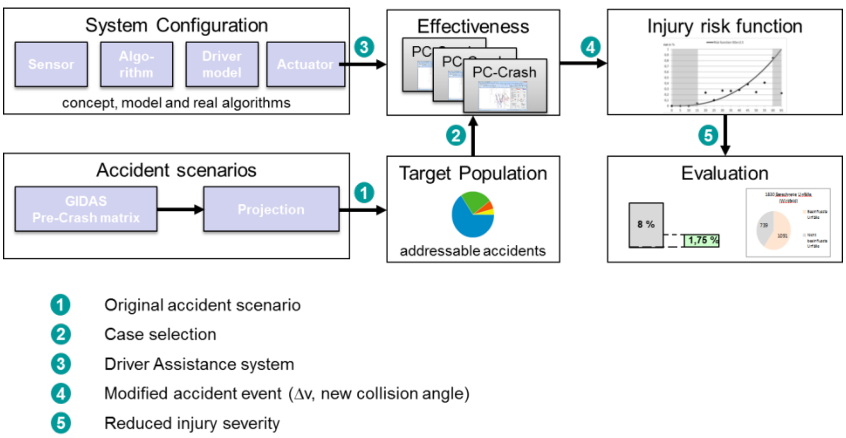

Figure 3: Effectiveness assessment in UR:BAN

DATA ANALYSIS (EXAMPLE)

In close cooperation with the application projects, the partners in WER developed and adjusted a “target population template” which allows filtering the overall urban accident scenarios by variables supposedly relevant to the sensor functions, algorithms or functional limitations. This harmonized template allows fast variation of the data analysis of more than 17,000 injured persons for the initial urban accident scenario in which a car was involved. By identifying accident conditions with a tick-box approach, relevant subsets based on combined characteristics can be extracted and compared in order to inform the developers on their system’s potentials.

These variables are either defining the overall conditions under which the accident occurred (weather, time of day, application area, trajectory) or vehicle-related data such as speed before the accident, driving maneuver or type of opponent (car, bicycle).

Some of the variables can be adopted directly from GIDAS, e. g. to analyze the data for weather conditions, since sensors could be influenced by snow or rain. Other variables are re-coded by using multiple GIDAS variables. E. g. the template variable “application area” describes the street type classified by aspects such as number of lanes, right of way and lane width. Fig. 4 shows an exemplary fictitious driver assistance system and how filtering leads to an addressed relevant subset of GIDAS cases. In this case, if the system is capable of addressing car-to-car lane change conflicts on straight roads with two lanes in one direction, a subpopulation of the urban accident remains as target population. The number of injured persons in relevant GIDAS cases is projected to national accident data by using the weighting factors (see paragraph PROJECTION)

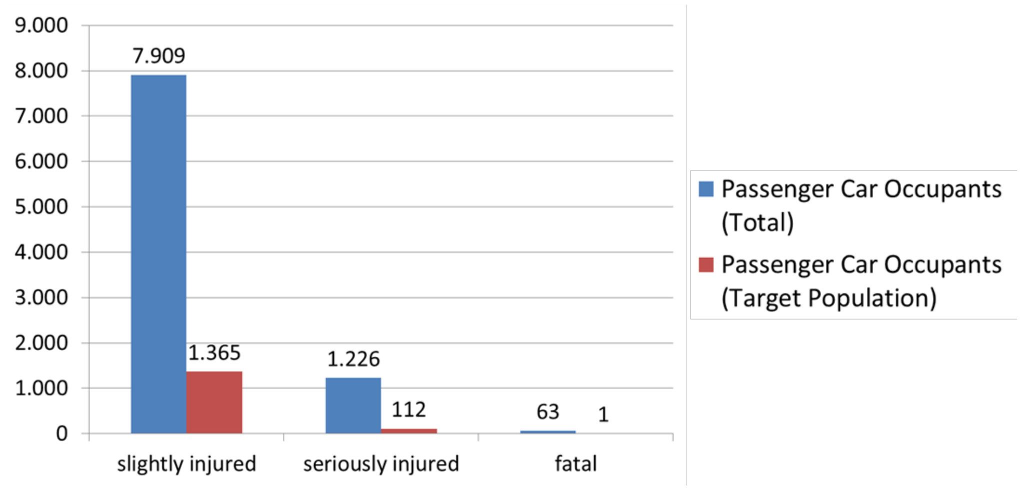

Figure 4: Example for target population analysis with WER template (own figure, GIDAS)

Another example for the WER contribution in UR:BAN is accident analysis focused on pedestrians and cyclists. The scope of the WER accident analysis conducted for SVT was to display relevant pedestrians and cyclists accident characteristics – and how they differ when accidents are aggregated to “SVT scenarios”. In addition to the generic WER template, these scenarios were defined based on sensor and function capabilities with regard to pedestrian and cyclist detection, using the GDV accident type. F1 covered all accident type scenarios in which a pedestrian was crossing the street without obstruction, while F2 stands for the scenario “crossing with obstruction. F3 aggregated all turning in scenarios. Hence, all further variables were cross-tabulated by these scenarios (F1, F2, F3 and bicycle scenarios) in the analysis of all severely and fatally injured pedestrians and cyclists in GIDAS. Data in the national accident statistics allows replicating this approach, not with all depth, but a larger number of cases.

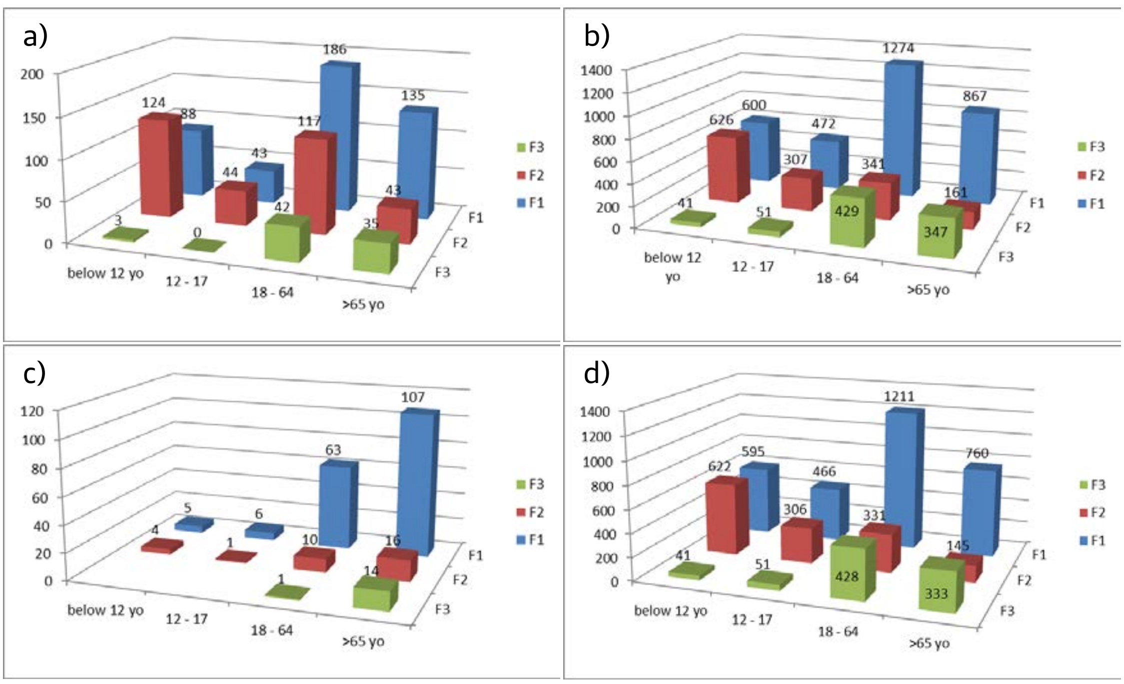

Figure 5: Pedestrians in SVT scenarios vs. age groups a) all severely and fatally injured in GIDAS b) all severely and fatally injured in DESTATIS (2008-2010) c) DESTATIS fatalities d) DESTATIS severely injured.

Fig. 5 shows that especially for insights on fatalities, this is a big advantage compared to GIDAS. Fig. 5 a) and 5 b) show a comparison of all severely and fatally injured in GIDAS (n = 860) by age group and scenario in comparison to all severely and fatally injured pedestrians in the national statistics sample (n = 5516). For the most important scenario F1, the age distribution matches well, for the obstruction scenario, children are more relevant in the larger sample. In 5 c) and 5 d), national accident data can be used to further distinguish severely from fatally injured pedestrians, which make it obvious that the elderly are at highest fatality risk across all scenarios.

In general, this analysis of a larger sample of accidents with vulnerable road users confirmed the conclusions drawn from GIDAS. The accident types 421 – pedestrian on straight road without obstruction from the right and 401 – the same scenario from the left – are the most important in both datasets.

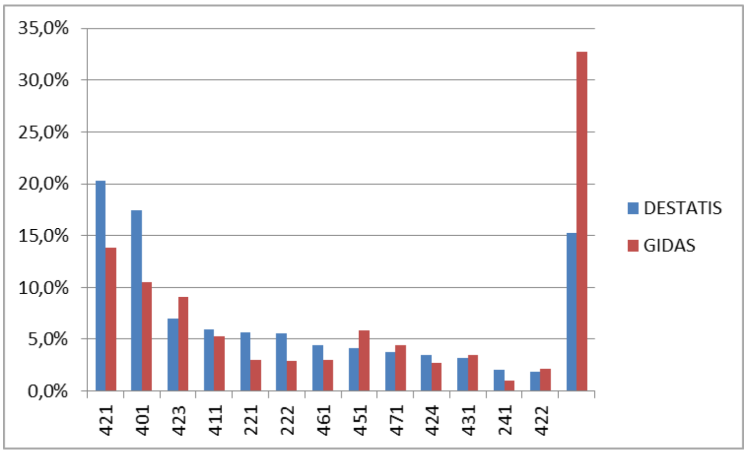

Figure 6: Comparison of relevant accident types (3- digit GDV) from GIDAS and DESTATIS sample

PROJECTION

GIDAS is approximately representative for the German accident scenario, since a random sample of all road traffic injury accidents is collected in two analysis sites. However, the number of cases collected each year and in total is small compared to the 300,000 accidents with at least one injured road user in Germany each year. Moreover, there are differences between the occurrence of accident constellations when comparing GIDAS with national statistics. Weighting the accidents within the GIDAS database, results from GIDAS can be both scaled up and corrected with an appropriate scaling-up method. In UR:BAN, the sub-project amended the two-stage approach used by Volkswagen which uses first accident distributions and corrects these figures by the real injury distributions in the second stage.

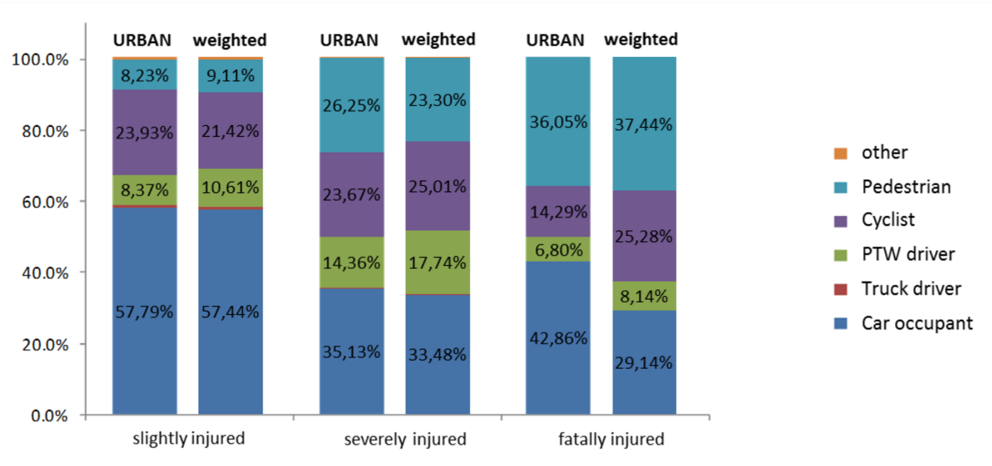

Figure 7: Urban accident where cars are involved: Injured road users in UR:BAN target population unweighted (left columns) and scaled up to German accident numbers 2012 (right columns).

Relevant variables that are matched to correct GIDAS to the national accident scenario of 2012 are kind of accident, location and accident severity, and on road user level, kind of participant and age for car occupants. Figure 7 shows, how this decreases the share of car occupants, but increases the relative importance of cyclists and powered two wheeler users.

The projection methodology uses correction factors that show a deviation supposedly meaningful for results to draw upon the GIDAS data, such as accident types (longitudinal, crossing, pedestrian) and road type. Hence, it is interesting to compare the projected figures with another significant accident statistics in the DESTATIS data – the number of injured road users by opponent type in urban accidents with at least one car involved [6, p. 103ff]. Figure 8 shows that for severely and fatally injured road users in the analysis of UR:BAN, the match shows a strong accordance of weighted GIDAS and the original figures.

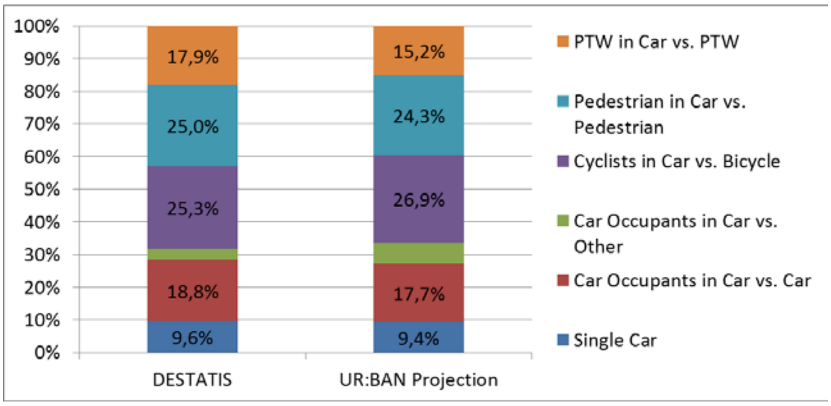

Figure 8: Comparison of weighted GIDAS data (UR:BAN target population) and DESTATIS data; fatally and severely injured road user in urban accidents with at least on car and with two participants maximum

SUMMARY AND DISCUSSION

Accident analysis may provide important impulses for the development of driver assistance systems. It is important to retrospectively analyze accident data by comparing target populations and determine the influence of system limitations on the one hand. On the other hand, prospective effectiveness evaluation may help discover further aspects of real accidents to consider in the development of these functions.
As a result, WER provides transparency and benefit from an evaluation of target populations and effectiveness of active driver assistance based on re-simulation of real-world accident data. Based on the accident analysis in UR:BAN, the applications developed in the UR:BAN project focus on the reduction of fatally and severely injured road users.

The WER subproject cooperates alongside the development process with the application projects in UR:BAN. Within the cooperation the target populations of UR:BAN driver assistance systems are iteratively optimized and various system performance parameters for the effectiveness simulation can be applied to find the best configuration of the system. The methodology makes use of the full information depth of GIDAS and projects findings based on GIDAS to German national accident figures.

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Frontal Corner Impacts – Crash Tests and Real-World Experience

D J Dalmotas*, A German* and P Prasad**

* D.J. Dalmotas Consulting Inc., 370 Chemin d'Aylmer, Gatineau, QC J9H 1A7, Canada
** Prasad Engineering, LLC, 10406 Millwood Drive, Plymouth, Michigan 48170, USA

Abstract - In North America, frontal crash tests in both the regulatory environment and consumer-based safety rating schemes have historically been based on full-width and moderate-overlap (40%) vehicle to barrier impacts. The combination of improved seat-belt technologies, notably belt tensioning and load limiting systems, together with advanced airbags, has proven very effective in providing occupant protection in these crash modes. Recently, however, concern has been raised over the contribution of narrower frontal impacts, involving primarily the vehicle corners, to the incidence of fatality and serious injury as a result of the potential for increased occupant compartment intrusion and performance limitations of current restraint systems. Drawing on data documented in the National Automotive Sampling System (NASS)/ Crashworthiness Data System (CDS) for calendar years 1999 to 2012, the present study examines the characteristics of existing and proposed corner crash test configurations, and the nature of real-world collisions that approximate the test environments. In this analysis, particular emphasis is placed on crash pulse information extracted from vehicle-based event data recorders (EDR's).

INTRODUCTION

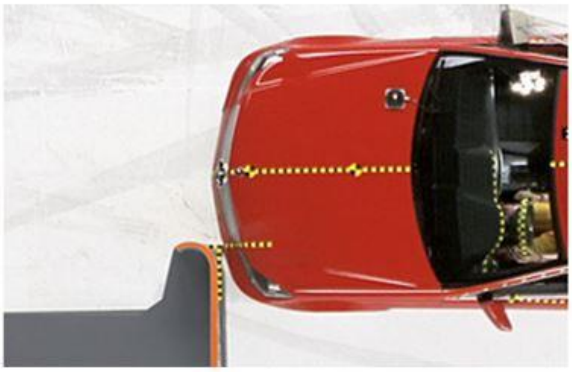
In North America, light-duty vehicles are subject to frontal crash tests in the regulatory environment and as part of consumer-based safety rating schemes. Historically, these tests have been based on full-width and moderate-overlap (40%) vehicle-to-barrier impacts. Improvements to occupant restraint technologies, notably seat-belt tensioning and load limiting systems, together with advanced airbags, have proven very effective in mitigating occupant injury in these crash modes. Recently, however, concern has been raised over the contribution of narrower frontal impacts, involving primarily the vehicle corners, to the incidence of both fatalities and serious injuries, as a result of the potential for increased occupant compartment intrusion and performance limitations of current restraint systems.

This has prompted both the Insurance Institute of Highway Safety (IIHS) and the National Highway Traffic Safety Administration (NHTSA) to investigate additional test configurations for frontal impacts. IIHS has implemented a 25% offset, frontal crash test, referred to as a Small Overlap Impact (SOI), as part of their safety rating scheme. In this test, the front rail of the vehicle is not engaged [1]. Meanwhile, NHTSA has embarked on a research project that would lead them to adopt a somewhat different small overlap test configuration. In a study of real-world fatal crashes, where belted occupants were further protected by air bag systems, structural interactions between the striking and the struck vehicles were judged to be inadequate [2]. NHTSA's proposed countermeasure is most likely to be an oblique-frontal test involving a small overlap between the front-end of a vehicle and a movable deformable barrier (MDB) [3].

The present study reviews data from a subset of real-world crashes captured as part of the National Automotive Sampling System (NASS)/Crashworthiness Data System (CDS) that approximate the conditions of crash tests undertaken by NHTSA. Crash pulse profiles and airbag firing times obtained from vehicle EDR's for both field collisions and crash tests are used in the evaluations. Opportunities to improve the field relevance of crash test configurations that have been developed to evaluate the levels of vehicle safety in frontal corner impacts are discussed.

METHODOLOGY

Drawing on data documented in NASS/CDS for calendar years 1999 to 2012, the present study examines the characteristics of existing and proposed corner crash test configurations, and the nature of real-world collisions that approximate the test environments. The analyses seek to quantify the nature of the frontal corner impact problem in the context of the residual frontal problem which produce serious or fatal injury in the 2000-on model year passenger vehicle fleet with emphasis on collisions which continue to result in serious-to-fatal head or chest injury.



IIHS Small Overlap Impact (above)

NHTSA Oblique-frontal Impact (right)

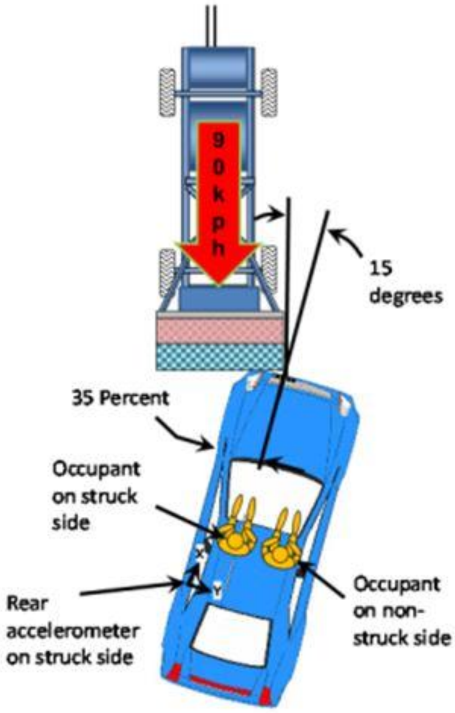


Figure 1. Small-overlap crash tests

Particular emphasis is placed on a comparison of crash pulses and airbag firing times for the subject vehicles based on the data obtained in field collisions and crash tests from on-board event data recorders for vehicles that were so equipped. The EDR data are drawn from an inventory of more than 7300 EDR reports documented as part of NASS and a further 255 reports downloaded from staged laboratory tests performed by NHTSA.

Event Data Recorders

The introduction of frontal airbags into North American vehicles, with their reliance on electronic sensors and microprocessor-based control systems, also saw the development of in-vehicle crash recorders. Early versions of these EDR's, notably those produced by General Motors, were limited to recording the vehicle's change in longitudinal velocity (delta-V) in 10 ms increments over either a 150 or 300 ms time interval. In addition, the EDR could capture certain occupant-related data such as seat belt use, and a time history (five, one-second snapshots) of pre-crash vehicle parameters such as travel speed, engine RPM, brake and throttle application [4)].

Over time, as more sophisticated occupant protection systems and collision avoidance technologies have been introduced into vehicles, the functionality of EDR's has been expanded to capture a wider range of parameters at a greater level of detail. In particular, current EDR's may include both longitudinal and lateral vehicle accelerations and/or delta-V's in 1 ms increments over a 250 ms time interval. [5] Additional data elements that may be recorded include the firing times for seat belt pre-tensioners dual-stage frontal air bags, head curtains, and knee bolsters. Pre-crash time histories of vehicle speed, engine speed (RPM), accelerator pedal and engine throttle position, and brake application may be recorded at 0.1 or 0.2 s intervals over a 5 s period. Data may also be recorded on the involvement of collision avoidance systems such as anti-lock brakes (ABS) and electronic stability control (ESC).

Prior research has shown that the crash-pulse data captured by EDR's installed in various vehicle makes and models that were subject to several types of staged collisions are accurate to within a few percent [5-7]. The delta-V obtained from the EDR is generally under-reported since the initial portion of the crash pulse is not processed due to the algorithm only being enabled after a preset vehicle acceleration threshold is reached. In the present paper, extensive use has been made of crash-pulse data obtained from vehicles that were equipped with EDR's and were either subject to crash tests or involved in real-world collisions.

RESULTS

Residual Belted Driver Safety Problem in Frontal Crashes

To gain insights on the nature of the residual frontal safety problem, the NASS/CDS database for calendar years 1999-2010 was examined to quantify the characteristics of frontal crashes which resulted in Maximum Abbreviated Injury Scale (MAIS) 3 or greater injury among belted drivers in vehicles fitted with frontal airbag systems. The analysis was confined to 2000 model year or newer vehicles involved in planar frontal collisions, with a Collision Deformation Classification (CDC) general area of damage of "F", and a direction of force assignment of 11 to 01 o'clock for the primary impact. Collisions involving secondary impact were permitted, but only if the damage extent associated with any non-frontal impact was confined to a CDC extent value of either 1 or 2. To be included in the sample, the age, gender and MAIS of the driver had to be known. Drawing on the injury data provided for vehicle occupants, drivers who sustained at least one head/face or chest injury of AIS 3 or greater were also identified.

	Weighted			**Raw**		
GAD1/SHL1 GROUP	**Exposed**	**MAIS>=3**	**AIS Head/Face and/or Chest>=3**	**Exposed**	**MAIS>=3**	**AIS Head/Face and/or Chest>=3**
FD	49.3%	**47.41%**	44.4%	48.9%	**51.5%**	51.0%
FY	12.5%	**21.71%**	25.3%	14.3%	**17.6%**	18.2%
FL	12.4%	**15.20%**	9.2%	12.6%	**14.7%**	15.9%
FR	12.5%	7.49%	12.0%	10.2%	5.4%	5.2%
FZ	12.2%	6.75%	7.5%	12.4%	7.6%	6.6%
FC	1.1%	1.45%	1.7%	1.6%	3.2%	3.2%
All	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Population Counts	**3,219,979**	**57,924**	**26,217**	**8,664**	**746**	**347**

Table 1. Composition of Driver Sample by General Damage Group

The driver sample consisted of 8,664 individuals representing 3,219,979 drivers when the NASS weights are applied. The subset of drivers with MAIS 3 or greater injury consisted of 746 individuals representing 57,924 drivers when weighted. Of the MAIS 3 or greater driver subset, 347 (26,217 when weighted) were determined to have sustained at least one AIS 3 or greater injury to either the head/face region and/or the chest region. The unweighted and weighted distributions of the exposed and injured driver populations, as a function of damage grouping based on the 3rd and 4th characters of the primary CDC, are depicted in Table 1. Here we can see that the "FD" (distributed) category accounted for the highest percentage of drivers injured at the AIS 3 or greater level. This was followed by the "FY" category (between 1/3 to 2/3 overlap of the front on the left side), and the "FL" category (less than 1/3 overlap of the front on the left side). This ranking order can be seen to apply for both the unweighted and weighted percentages. In the case of the injured driver subsets, the representation of "far" side impacts, "FZ" and "FR", is low except for the weighted "FR" estimate (12%) among drivers who sustained at least one AIS 3 or greater head/face or chest injury. The weighted estimate is at odds with the unweighted percentage (5.2%). Examination of the NASS weights associated with this subset of drivers revealed that two of the crashes had very elevated weights accounting for 80% of the weighted "FR" estimate.

The driver subset was partitioned into four areas of damage/direction of force groupings. The first of these consisted of "FL" impacts with a principal direction of force (PDOF) of 11 or 12 o'clock. The second grouping consisted of "FY" impacts with a PDOF of 11 or 12 o'clock. These assignments were done to render the groupings more consistent with crash testing protocols addressing SOI and oblique frontal impacts. The third grouping consisted of "FD" with a PDOF of 11 or 12 or 01 o'clock. The remaining area of damage and direction of force pairings were consolidated in the "Other" category. From the distributions presented in Table 2, it can be observed that, for all four defined groupings, 12 o'clock direction of force crashes predominate.

		Weighted			**Raw**		
GAD1/SHL1 DOF GROUP	**PDOF**	**Exposed**	**MAIS>=3**	**AIS Head/Face and/or Chest >=3**	**Exposed**	**MAIS>=3**	**AIS Head/Face and/or Chest >=3**
FL, PDOF= 11, 12	11 O' Clock	1.9%	1.09%	0.6%	2.7%	2.3%	2.3%
	12 O' Clock	**10.2%**	**14.11%**	**8.6%**	**9.7%**	**12.5%**	**13.5%**
FY, PDOF= 11, 12	11 O' Clock	3.4%	1.62%	2.1%	3.6%	2.4%	2.6%
	12 O' Clock	**8.2%**	**19.08%**	**21.8%**	**9.6%**	**13.9%**	**13.8%**
FD, PDOF= 11, 12, 01	01 O' Clock	5.5%	5.34%	2.4%	8.4%	6.6%	4.0%
	11 O' Clock	7.2%	5.26%	2.8%	9.1%	6.3%	4.9%
	12 O' Clock	**36.6%**	**36.80%**	**39.2%**	**31.4%**	**38.6%**	**42.1%**
OTHER	01 O' Clock	6.8%	4.95%	8.6%	7.1%	3.8%	4.9%
	11 O' Clock	1.5%	0.71%	0.1%	1.2%	0.4%	0.3%
	12 O' Clock	**18.8%**	**11.03%**	**13.8%**	**17.2%**	**13.3%**	**11.5%**
All		100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Population Counts		**3,219,979**	**57,924**	**26,217**	**8,664**	**746**	**347**

Table 2. Composition of Driver Sample by Direction of Force

The above driver subsets were further partitioned by CDC damage extent intervals. Three intervals, CDC damage extents 1-2, damage extents 3-6, and damage extents 7-9, were defined. The middle damage extent interval, 3-6, corresponds closely with the range of CDC damage assignments typically associated with existing frontal regulatory tests, as well as the CDC extent assignments observed in SOI and oblique crash tests. From the results presented in Table 3, it can be seen that, in the case of "FD" and "FY" crashes, this CDC extent interval accounts for the majority of drivers with AIS 3 or greater injury.

		Weighted			Raw		
GAD1/SHL1 DOF GROUP	**CDC Extents**	**Exposed**	**MAIS>=3**	**AIS Head/Face and/or Chest >=3**	**Exposed**	**MAIS>=3**	**AIS Head/Face and/or Chest >=3**
FL, PDOF= 11, 12	1 to 2	5.4%	3.50%	2.0%	4.8%	2.4%	2.6%
	3 to 6	4.8%	**6.58%**	**3.9%**	5.4%	**6.3%**	6.1**%**
	7 to 9	1.9%	5.12%	3.2%	2.3%	6.0%	**7.2**%
FY, PDOF= 11, 12	1 to 2	10.0%	7.05%	11.7%	9.8%	3.4%	2.0%
	3 to 6	1.4%	**13.59%**	**12.1%**	3.3%	**12.6%**	**13.5%**
	7 to 9	0.1%	0.07%	0.1%	0.1%	0.4%	0.9%
FD, PDOF= 11, 12, 01	1 to 2	45.1%	14.70%	10.9%	40.1%	16.6%	11.5%
	3 to 6	4.0%	**31.05%**	**31.7%**	8.2%	**31.6%**	**34.6%**
	7 to 9	0.1%	1.65%	1.7%	0.6%	3.2%	4.9%
OTHER	1 to 2	17.8%	6.93%	9.1%	16.6%	5.5%	4.0%
	3 to 6	7.2%	**8.21%**	**10.7%**	7.3%	**10.1%**	**10.7%**
	7 to 9	2.1%	1.55%	2.7%	1.5%	1.9%	2.0%
All		100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Population Counts		**3,219,979**	**57,924**	**26,217**	**8,664**	**746**	**347**

Table 3. Composition of Driver Sample by Damage Extent

EDR Field Data

Currently EDR data, in the form of individual EDR reports, are available for over 7,300 vehicles represented in NASS. These reports were secured and stored on a local server so as to allow direct access to the reports via links embedded in Excel databases of the NASS cases of interest. Although data reporting formats vary widely, data elements such as the maximum longitudinal velocity change and frontal airbag fire times are common to almost all of the EDR reports. These data are summarized in Figures 2 and 3 for EDR field cases drawn for NASS calendar years 2001-2010 and in Figures 4 and 5, for EDR field cases drawn for NASS calendar years 2011-2012. Note that whereas the 2001-2010 data reflect vehicle pairings to belted drivers, the vehicle pairings in the 2011-2012 data are based solely on vehicle damage. The 2011-2012 data analysis was undertaken to capture maximum lateral velocity change data. Such data are typically only available for newer vehicle models fitted with side airbag protection. The lateral velocity change data obtained from the 2011-2012 NASS database are summarized in Figure 6.

EDR Crash Test Data

EDR reports are also available for many of the crash tests conducted by NHTSA [8]. As in the case of the NASS EDR reports, the crash test EDR reports were secured and stored on a local server so they too could be accessed via Excel databases. To date, a total of 255 NHTSA crash test EDR reports have been obtained. The EDR vehicle velocity change and airbag fire time data for the subset of crashes identified as either “SOI” or “OBL” in NHTSA’s vehicle database are summarized in Figures 7-9. These are accompanied by vehicle velocity change and airbag fire time data in frontal NCAP tests performed in 2012 and for which EDR data were available.

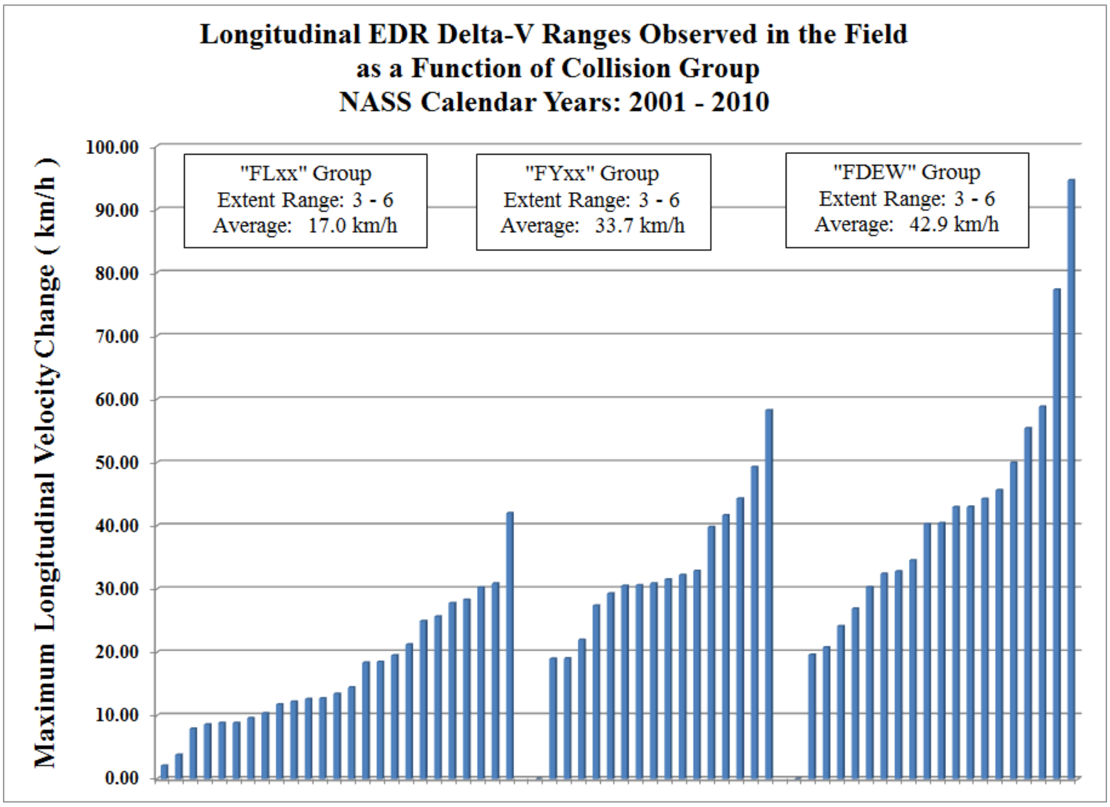


Figure 2. Longitudinal Delta-V in 2001-2010 NASS Cases

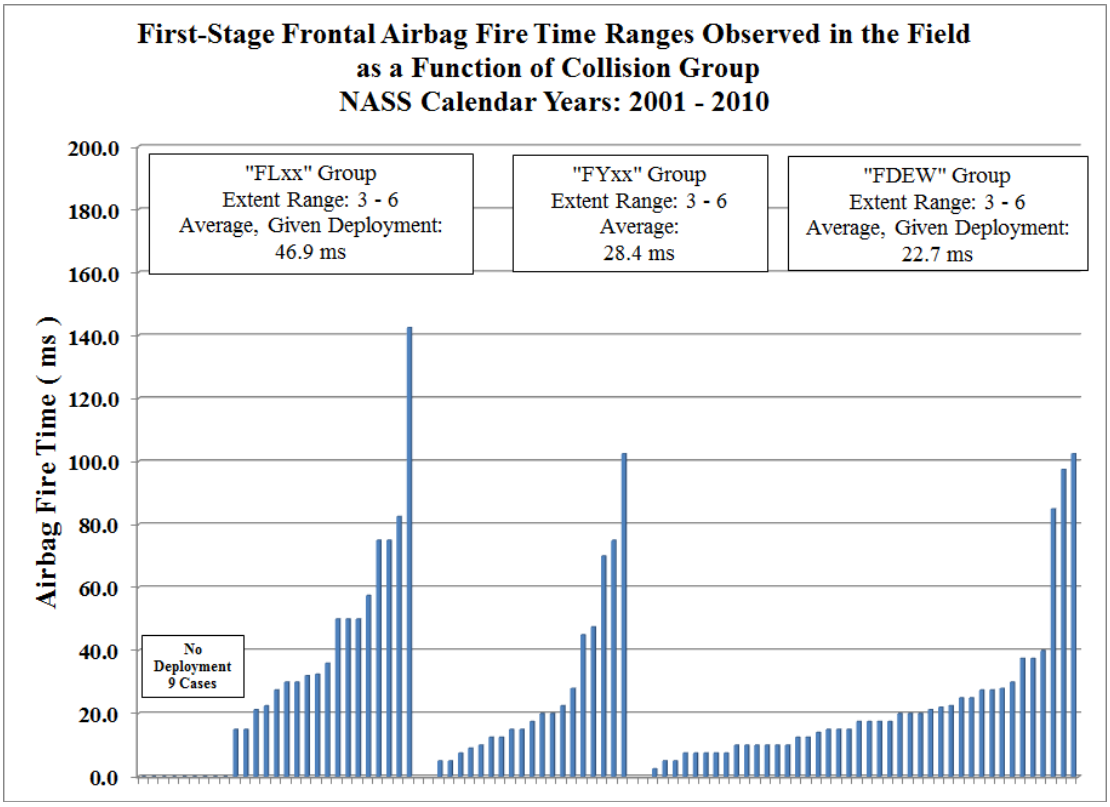


Figure 3. Frontal Airbag Fire Times in 2001-2010 NASS Cases

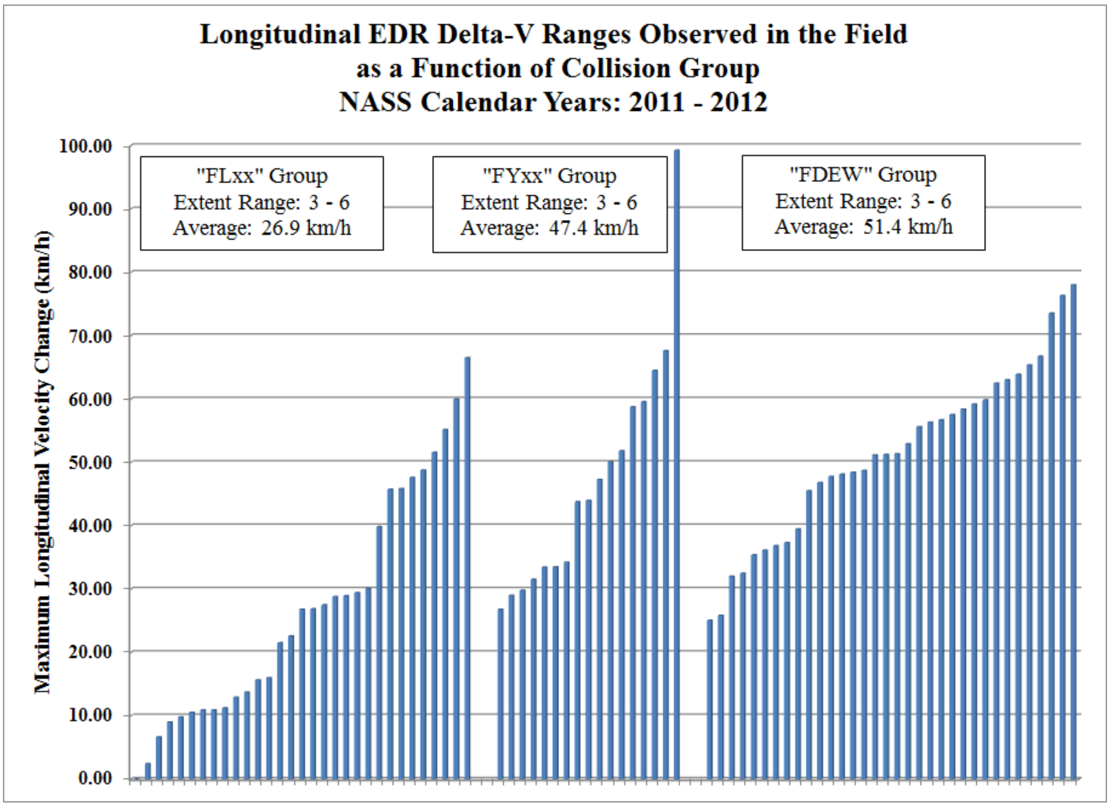


Figure 4. Longitudinal Delta-V in 2011-2012 NASS Cases

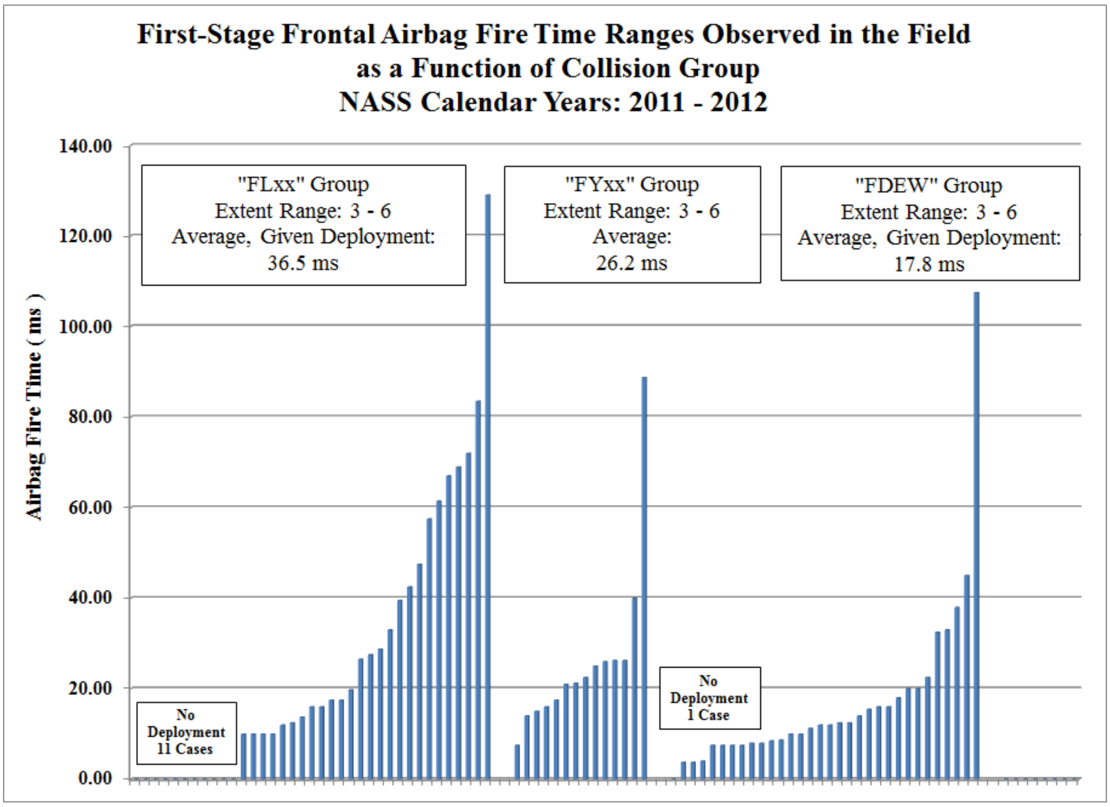


Figure 5. Frontal Airbag Fire Times in 2011-2012 NASS Cases

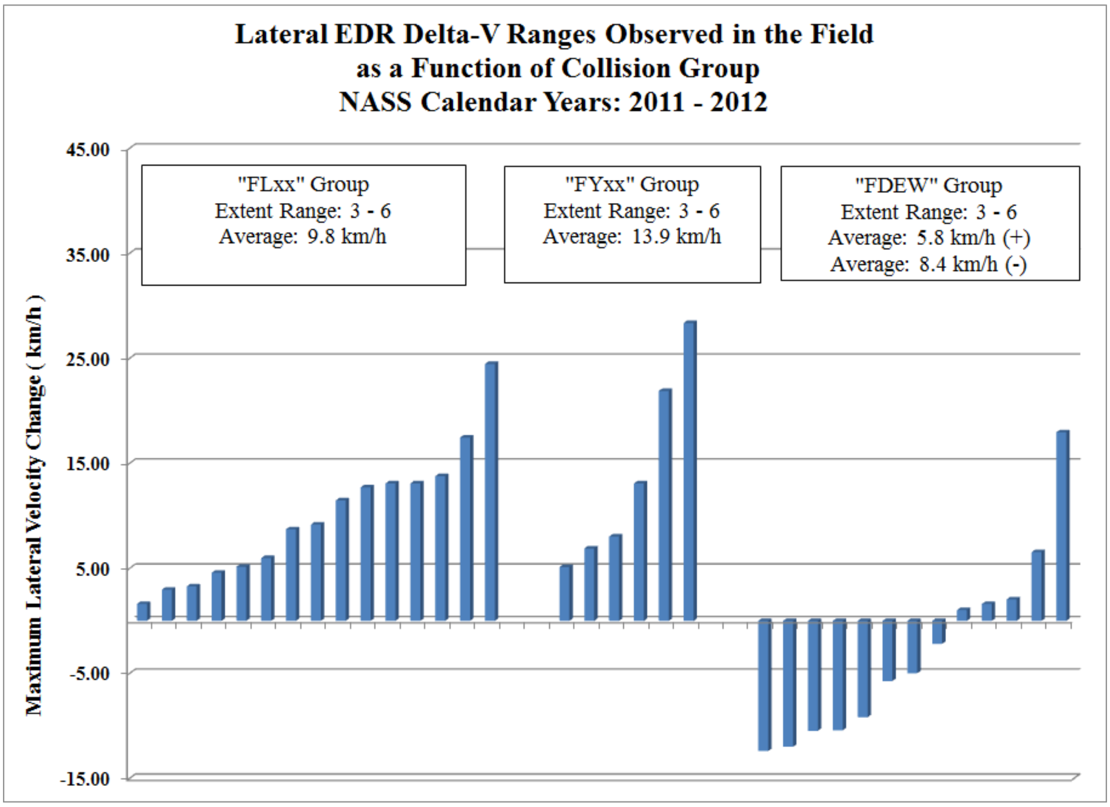


Figure 6. Lateral Delta-V in 2011-2012 NASS Cases

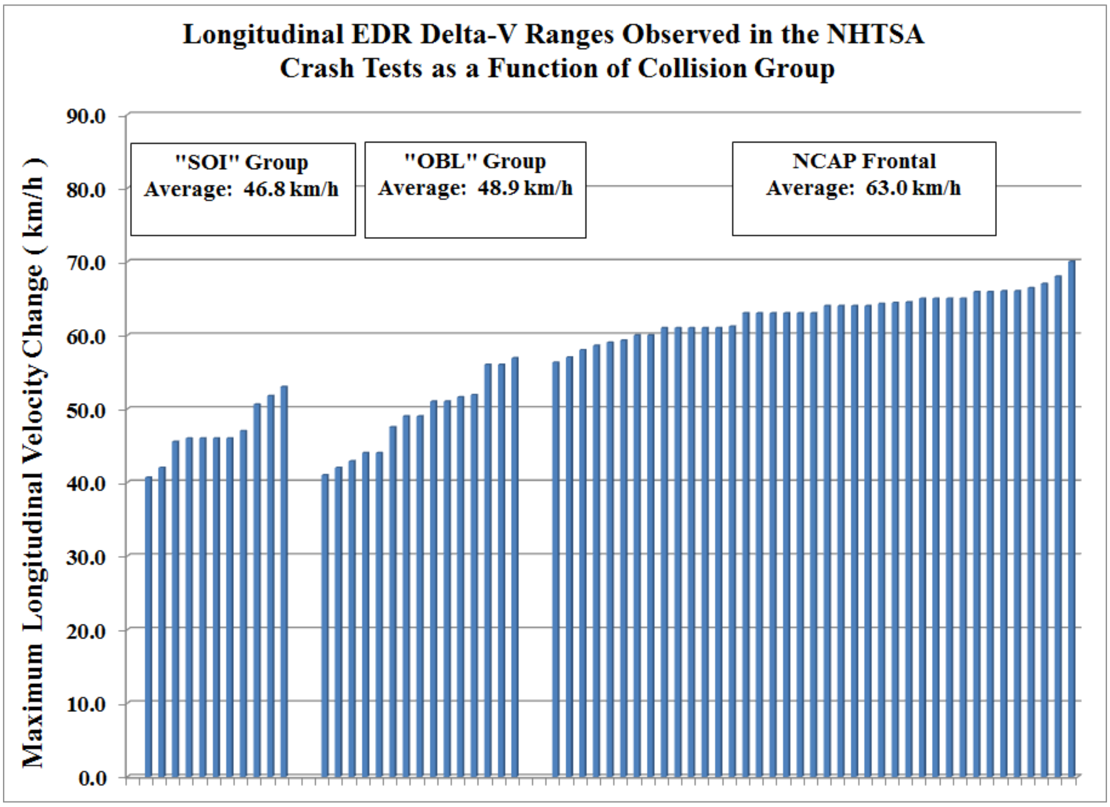


Figure 7. Longitudinal Delta-V in NHTSA Crash Tests

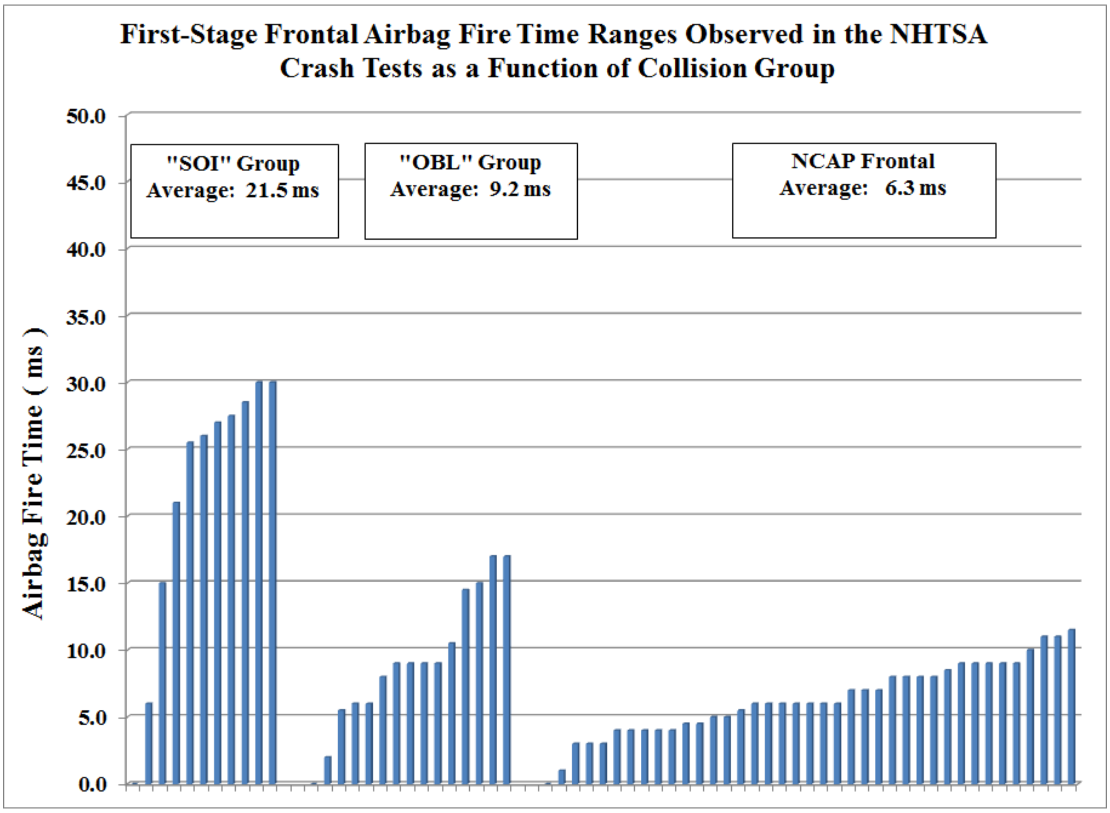


Figure 8. Frontal Airbag Fire Times in NHTSA Crash Tests

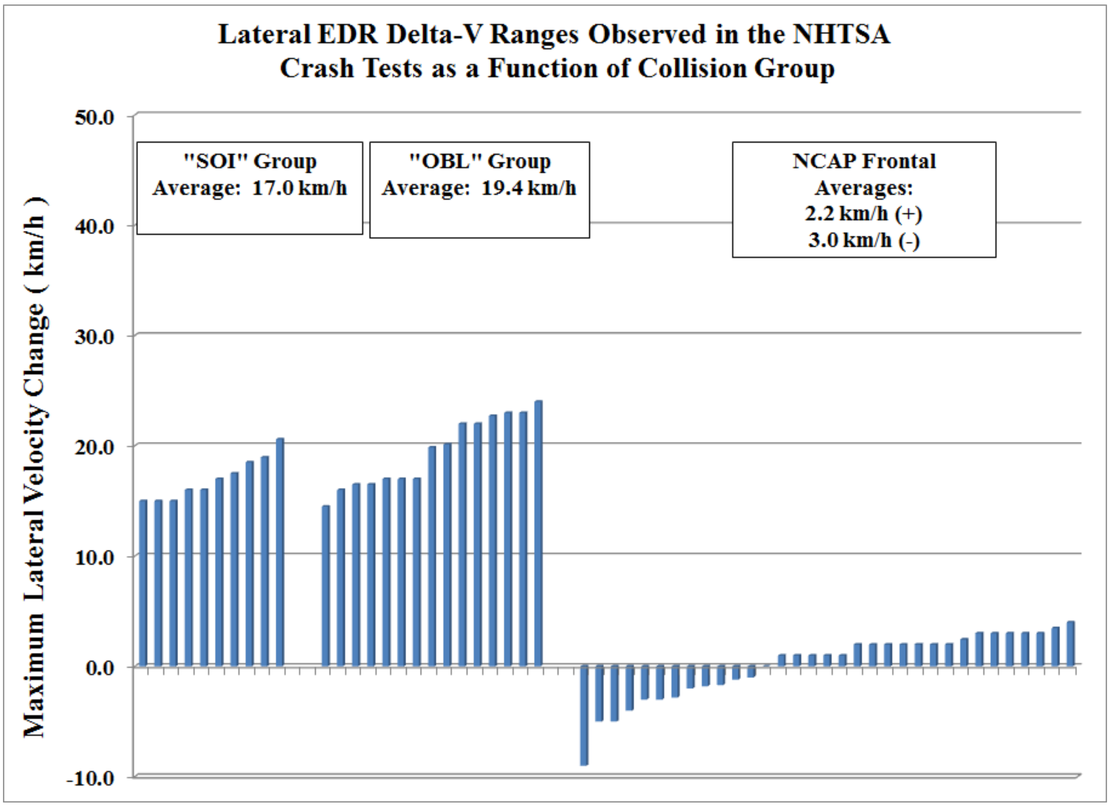


Figure 9. Lateral Delta-V in NHTSA Crash Tests

When we compare the crash test EDR data with the field EDR data, we can see that the airbag fire times and lateral velocity changes recorded in staged crash tests differ greatly from those recorded in the field. Note that the airbag "fire times" denote the time between when the collision sensing algorithm is "woken up" and the time when the command is issued to initiate deployment of the airbag. From the data presented in Figure 8, it can be seen these decisions are made earlier in crash tests than in the NASS cases for which EDR data are available. What is particularly striking is the amount of overlap between the firing times observed in "OBL" tests and those observed frontal NCAP tests. Recorded airbag fire times of the order of 10 milliseconds or less are infrequently observed in field collisions in the FLxx and FYxx groups. As shown in Figure 3, in only 5 out of 37 cases in these groups, the recorded airbag fire times are less than or equal to 10 ms. Similarly, Figure 5 shows that 5 out of 40 cases in the FLxx and FYxx groups have recorded airbag firing times of less than or equal to 10 ms. Based on limited EDR data, the EDR lateral velocity changes recorded in NHTSA's SOI and OBL crash tests (Figure 9) appear to be more elevated than those recorded in the field (Figure 6). Further analysis on these issues will be conducted as more EDR data become available in NASS.

DISCUSSION AND CONCLUSIONS

Historically, testing protocols employed in regulations have attempted to advance safety by presenting collision environments which are sufficiently severe to promote the fitment of new safety technologies or structural changes to the design of the vehicle. With the advent of technologies such as airbags, the operation of which is being influenced by the crash environment it is experiencing, it becomes important to ensure that testing protocols are field relevant in terms of the collision environment they impose on the vehicle.

The analyses presented in this paper are somewhat preliminary in nature, being limited by the number of cases involving EDR's, and the lack of consistency in the data obtained from these devices, in both staged crashes and real-world collisions. Nevertheless, the data that are available are indicative of the power of this relatively new tool for safety researchers.

In particular, EDR's can play a vital role in the process of developing improved test methods. Not only do they afford a means of quantifying the nature of the residual safety problem, but they can also assist in developing and validating testing protocols. Implementing testing protocols that are field relevant provides the most efficient means of ensuring that safety systems and vehicle structures are optimized in terms of their performance.

Relative to current efforts to develop testing protocols to assess frontal corner safety using an MDB, the initial review of available field EDR data suggests that these protocols would benefit from changes in the shape, stiffness and mass of the MDB, in addition to a reduction of the impact angle. These changes would promote airbag firing times and lateral vehicle responses that are more consistent with those observed in the field.

ACKNOWLEDGMENTS

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STATISTICAL DRIVER MODEL FOR ACCIDENT SIMULATION

Using a statistical driver model for benefit estimation of advanced safety systems with warning interfaces

Dipl.-Ing. (FH), M. Eng. C. Erbsmehl (1), Dipl.-Ing H. Schebdat (2)
1- Fraunhofer Institute for Transportation and Infrastructure Systems IVI, Germany
2- Adam Opel AG

Abstract - The main focus of the benefit estimation of advanced safety systems with a warning interface by simulation is on the driver. The driver is the only link between the algorithm of the safety system and the vehicle, which makes the setup of a driver model for such simulations very important. This paper describes an approach for the use of a statistical driver model in simulation. It also gives an outlook on further work on this topic.
The build-up process of the model suffices with a distribution of reaction times and a distribution of reaction intensities. Both were combined in different scenarios for every driver. Each scenario has then a specific probability to occur.
To use the statistical driver model, every accident scene has to be simulated with each driver scenario (combinations of reaction times and intensities). The results of the simulations are then combined regarding the probabilities to occur, which leads to an overall estimated benefit of the specific system.
The model works with one or more equipped participants and deliver a range for the benefit of advanced safety systems with warning interfaces.

INTRODUCTION AND MOTIVATION

The benefit estimation of autonomous advanced safety systems is often executed by real world accident simulations [1]. Figure 1 shows the functional principle of such a simulation process.

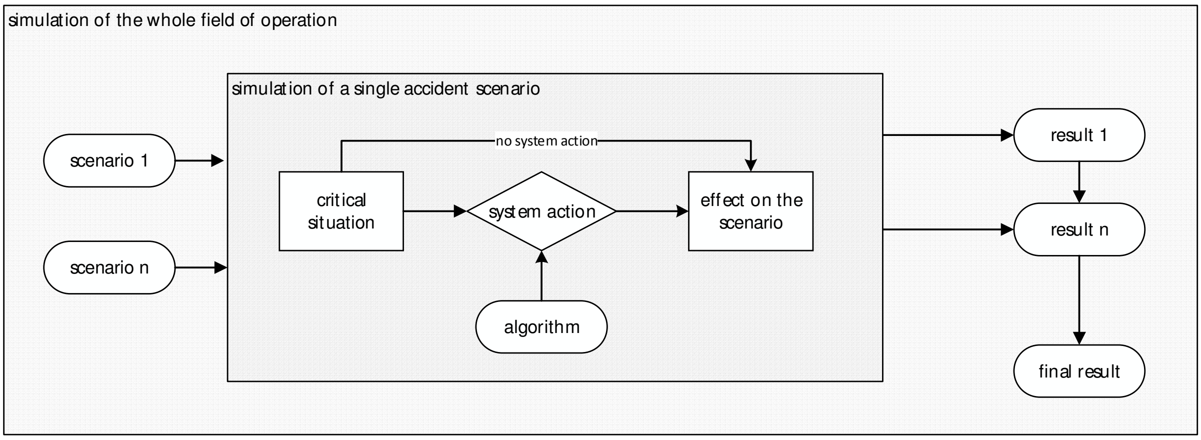

Figure 1: simulation process for autonomous advanced safety systems

A significant number of real world accident scenarios in the field of operation of the safety system is one requirement for the simulation process. These accident scenarios are then simulated one by one until the collision occurs. During the simulation of the accident scenarios, the participants of interest are equipped with the safety system sensor(s) and algorithm(s). Those algorithms are able to initiate a system interaction when a critical situation is detected. The system interaction (braking/steering) can have an effect to the whole accident scenario, leading to a mitigation or avoidance of the accident scenario. Based on the system complexities and functional safety requirements, most of the advanced safety systems on the market combine an autonomous interaction with a previous warning to initiate a driver reaction. A driver reaction after the warning can be used as a confirmation that a critical situation is imminent. For those warning systems, the driver requires an additional step within the simulation process, which leads to a more complex benefit estimation.

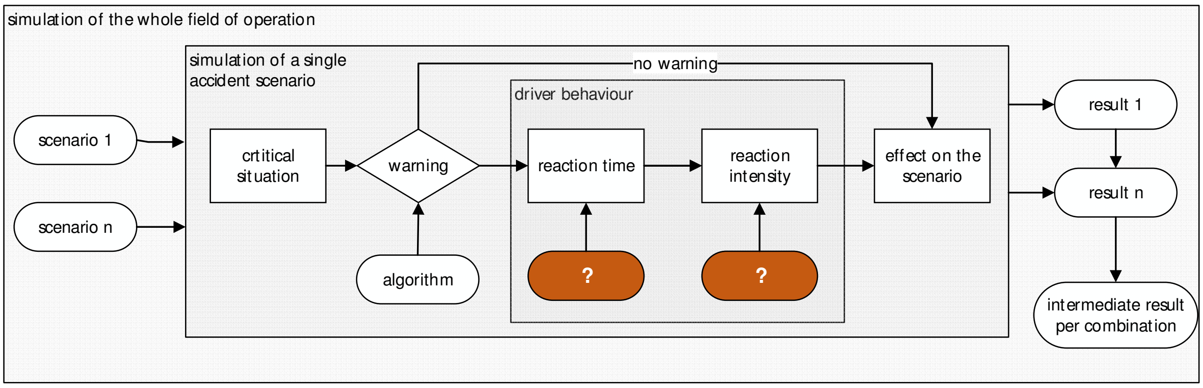

Figure 2: simulation process for warning safety systems

Figure 2 shows the functional principle of the simulation process including a warning system. The difference to Figure 1 is the driver behavior, which can be described with the reaction time and the reaction intensity. The warning safety system can only have an effect on the accident scenario if there is a specific response of the driver. The driver behavior model can have different complexities. The following paper will describe one method to define a driver model in a statistical way and gives some examples of results.

Main target

The aim of the statistical driver model is to define parameters for the driver reaction time and reaction intensity in a way that fit all possible scenarios regarding their single probabilities to occur. This driver model should then be used to execute a benefit estimation of a warning system.

APPROACH

In general, every driver shows an individual behavior and reaction based on a critical traffic situation. Based on different parameters such as age, driving experience, distraction, situation judgment, warning type, etc., the driver reaction will (or will not) occur with a specific intensity after a specific reaction time.

To reach the main target of the publication, the following three steps are required:

- Definition of the reaction intensity distribution
- Definition of the reaction time distribution
- Implementation into the simulation

Definition of the reaction intensity distribution

In this case, the driver reaction type “braking” is focused. It should be consensus that not every driver brakes with the same intensity after a critical situation occurs or after the warning of a safety system is given to the driver. This topic was also investigated by Felix Klanner in [2]. The following table of successful and unsuccessful reactions to the warning of advanced safety systems is one intermediate result of [2].

Table 1: intermediate results of Felix Klanner [2]

	successful reaction	unsuccessful reaction	Number
without warning	8%	92%	20
with warning	75%	25%	25

Table 1 shows the success of driver reactions on a system warning after a critical situation occurs. This means that 75% of the all drivers who did show a brake reaction related to the system warning avoided a potential collision. Within this study, different warning types were combined. This leads to the first assumptions for this paper:

If there is a reaction on the warning of a safety system:

- 75% of the drivers perform a brake maneuver with a high deceleration; → 100% brake pressure and
- 25% of the drivers perform a medium brake maneuver; → 50% brake pressure.

Definition of the reaction time distribution

After the intensity of the driver reaction was defined, the driver reaction time is mandatory for the estimated benefit. This distribution was already investigated by Wolfgang Hugemann [3].

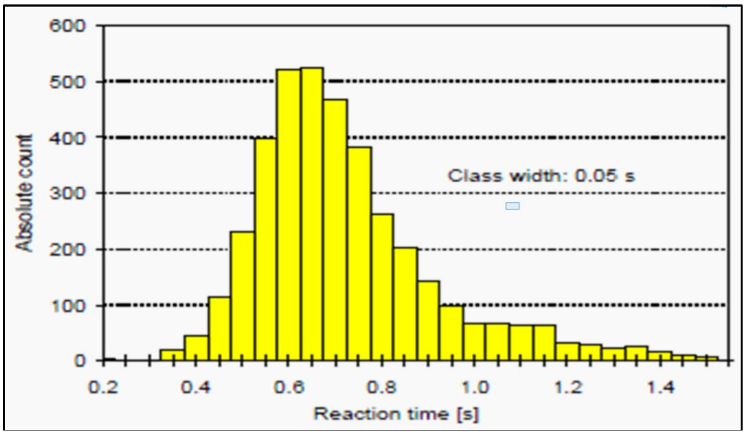

Figure 3: distribution of reaction times, W. Hugemann [3]

Figure 3 shows the distribution of the reaction times in 0.05s steps. Based on the different parameters mentioned above, the reaction times spread between 0.35s to 1.5s. To limit the calculation effort, the reaction times will be divided in three homogenous groups and a mean value of each group is calculated. The following table shows the mean reaction time of each group related to the probability.

Table 2: mean reaction times and probabilities

group	probability	mean reaction time
1	35%	0.48s
2	36%	0.70s
3	29%	1.08s

These reaction times (0.48s, 0.7s and 1.08s) will be used for the further calculations.

Implementation into the simulation

The last step of this approach is the implementation of the reaction times and intensities into the real world accident simulation. Figure 4 shows all possible combinations for one single driver which are the basis for the implementation into the simulation model.

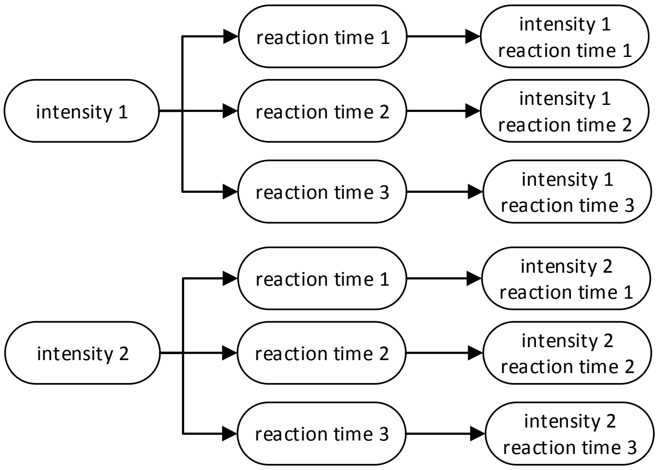

Figure 4: possible combinations for a single driver

Each accident scenario will be simulated with all possible combinations of reaction time and brake intensity. Figure 5 shows the functional principle of this procedure.

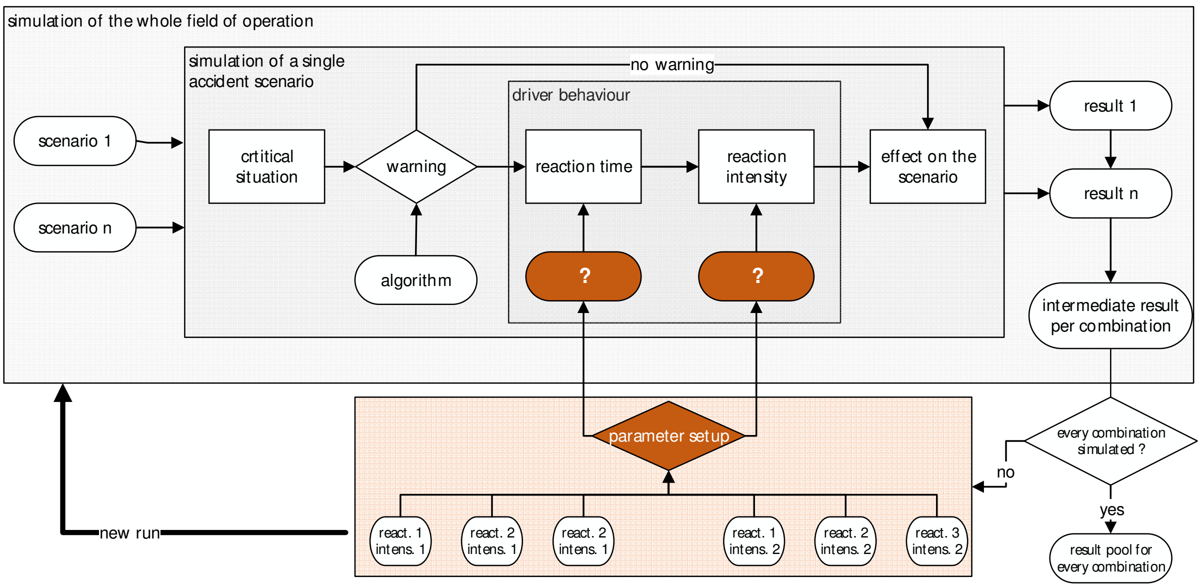

Figure 5: simulation process for warning systems with driver behaviour

The result of this extensive simulation process is a huge dataset of possible intermediate results. The size of this dataset depends on the number of accident scenarios in the field of operation and the number of possible driver behavior combinations. Figure 6 shows some possible result datasets for six combinations.

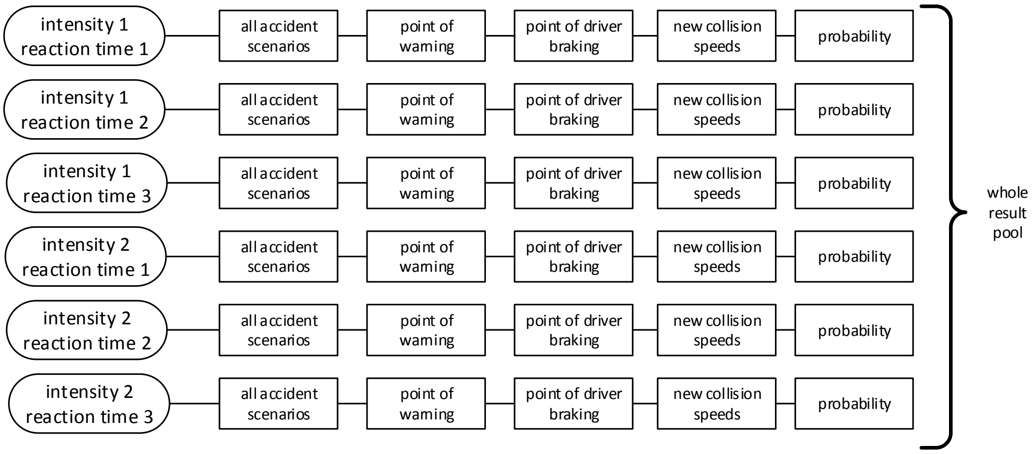

Figure 6: possible results for six combinations

Due to the fact that every accident scenario can be avoided or mitigated only once, a choice of the results of interest has to be made. This choice is made randomized led by the probability of every combination. The summation of all chosen single results produces one possible and plausible intermediate result. The random choice of the combinations lead to a variation of the intermediate results. To explain this variation, the following example is given:
If all fast reactions with high brake intensities are randomly addressed to accidents with a higher potential for avoidance or accident mitigation, a huge benefit of the investigated system will be the result. If all slow reactions with low brake intensities are addressed to this group, the benefit of the investigated system will be very low.
This results in an approach in which the benefit of the system is between a high and a low border. To define these borders, the random choice will be repeated until no significant change of the borders will appear. In a final step, the final result will give a tolerance band for all parameters of interest such as new collision speeds, points of driver braking or points of system warnings.

EXAMPLES

To give a deeper understanding for the usage of the statistical driver model, two examples will be shown in this chapter. One for a single driver and one for two drivers. The PCM [4] and some additional GIDAS [5] data is used as a basis for the simulations.

Single driver example

For the first example, pre-defined sensor systems and warning algorithms of the Adam Opel AG are used to simulate accident scenarios of a specific field of operation. The simulations were carried out using the simulation model of the Fraunhofer IVI.
Initially the probabilities for all possible combinations of the driver behaviour are calculated.

Table 3: possible combinations and dedicated probabilities (single driver)

single driver equipped			
combination	**reaction time [s]**	**brake intensity [%/100]**	**probability [%/100]**
1	0.48	0.50	0.0875
2	1.08	1.00	0.2625
3	0.70	0.50	0.0900
4	0.70	1.00	0.2700
5	1.08	0.50	0.0725
6	1.08	1.00	0.2175

Table 3 shows all possible combinations of reaction time and brake intensity of the statistical driver model of a single driver.

In this example, the field of operation of the specific warning system gives 3,172 accident scenarios in the PCM [4]. Every accident is then simulated with each combination of table 3. This gives a pool of simulation results of 19,032 scenarios. After the simulation, the result files have to be combined by the probability of each combination in a random way until there is no significant change of the whole result. This means for example that 27% of all accidents get the combination 4 (0.7s reaction time / 100% brake intensity). The choice of the 27% accidents is performed randomly.

Table 4: statistical variation of simulation results

configuration scenario	**1**	**2**	**3**	**4**	**5**	**...**	**100**
Accident number	combination	combination	combination	combination	combination	combination	
1	2	6	3	4	2	...	1-6
2	6	2	2	1	6	...	1-6
3	5	2	6	1	6	...	1-6
4	6	4	6	4	4	...	1-6
5	2	2	4	2	1	...	1-6
6	4	3	6	6	2	...	1-6
7	2	1	3	6	4	...	1-6
8	3	2	4	6	5	...	1-6
9	4	6	5	2	2	...	1-6
10	1	2	6	6	5	...	1-6
11	6	3	6	6	1	...	1-6
12	6	6	3	2	2	...	1-6
13	5	6	6	4	6	...	1-6
14	4	3	2	2	3	...	1-6
15	1	2	3	4	3	...	1-6
16	6	6	1	5	6	...	1-6
17	4	2	4	4	4	...	1-6
...							
3127							
	result 1	**result 2**	**result 3**	**result 4**	**result 5**	**result ...**	**result 100**
minimal effect of all results							
maximal effect of all results							

The comparison of the results after 100 different combinations delivers no further significant change in the overall result.

The following picture shows all 100 result files plotted in one single diagram.

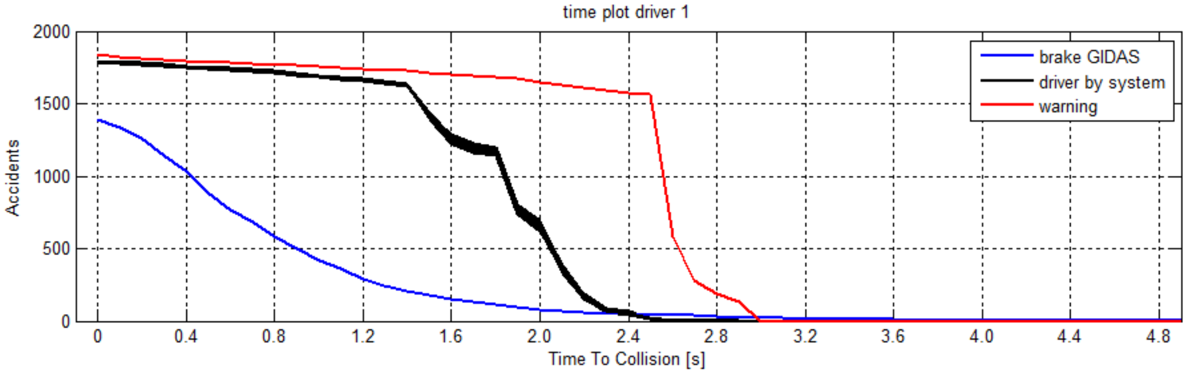

Figure 7: time plot for single driver example

Figure 7 shows the sum of all accidents where an original braking (GIDAS), a system warning and a warning-initiated braking (driver by system) related to the time to collision (TTC). The bold line of the 'driver by system' attracts attention and will be zoomed in in the next figure in the range of 1,000 to 1,400 accidents at the position of 1.6s to collision.

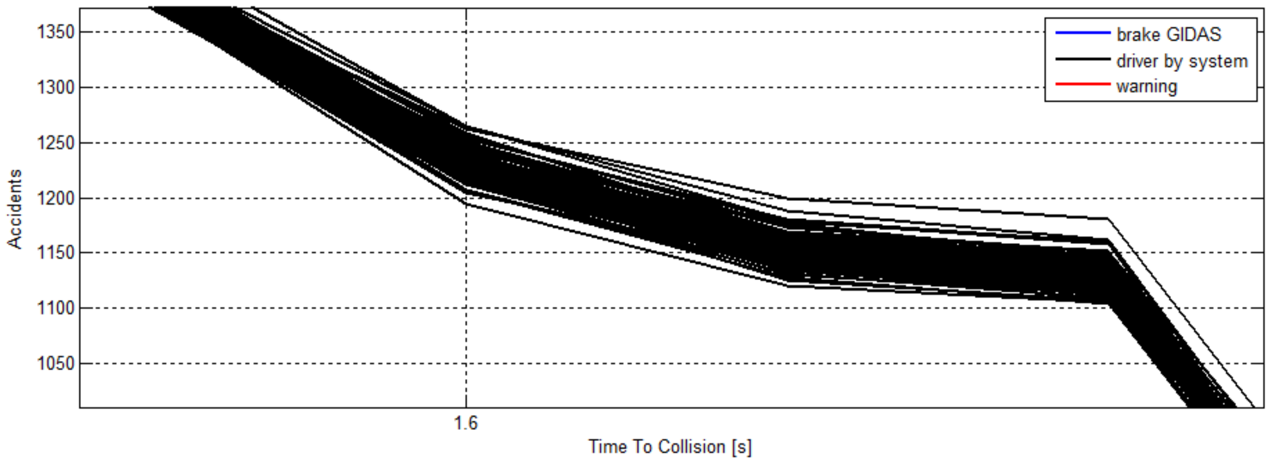

Figure 8: Enlargement of time plot (single driver example)

The enlargement in Figure 8 shows that the bold line in Figure 7 is based on the 100 different lines of the result dataset. These 100 lines are the result of the variation of the driver behaviour by their probability. It shows a spread of 80 accidents as a tolerance value at TTC= 1.6 s.

The next result parameters for this example are the collision speeds of the participant who was equipped with the warning system for the whole field of operation.

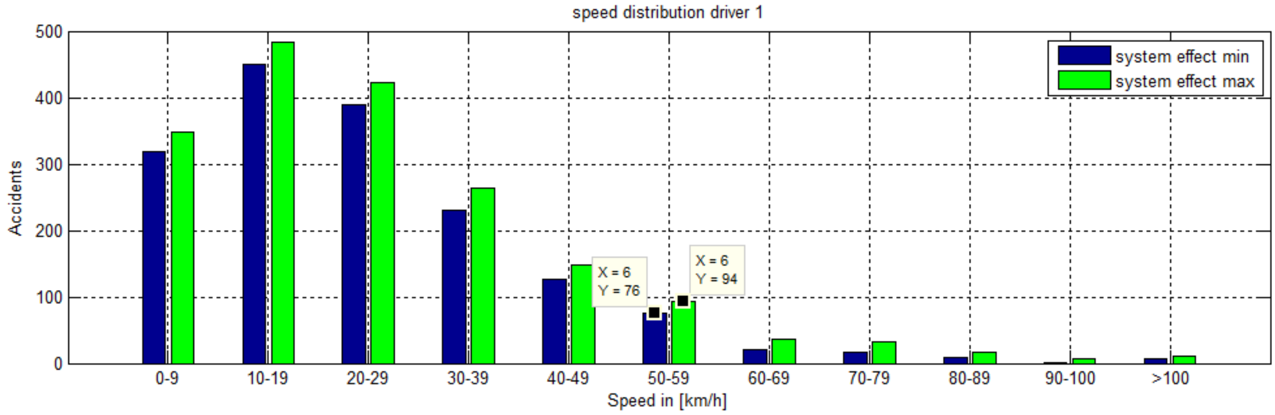

Figure 9: distribution of collision speeds of driver 1 (single driver example)

Figure 9 shows the number of accidents, divided by collision speed groups. Avoided accidents are not considered in this bar plot. This graphic shows also a tolerance band of results for each collision speed group. In group 6 (50-59 km/h), a spread of 18 accidents can be identified. This spread is the result of different driver behaviour by reacting on the same warning algorithm. The varying driver behaviour of driver 1 influence also the second accident participant (driver 2). The following bar plot shows this direct influence.

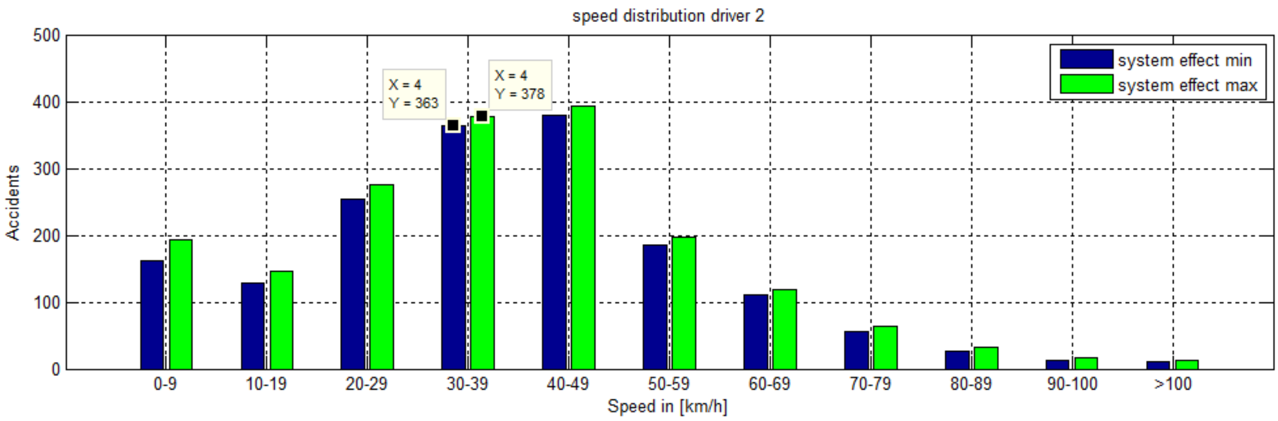

Figure 10: distribution of collision speeds of driver 2 in the single driver example

The differences in the collision speeds of the participant 2 are linked to the varying accident sequence caused by the varying driver behaviour of driver 1.

The variation of the driver behaviour related to the probability to occur produces different results depending on the assignment of the combinations to the different accident scenarios. Thus, the necessity arises to take into consideration the varying driver behaviour while estimating the benefit of warning safety systems using accident simulations.

Example for two drivers

The developed statistical driver model will be applied to two drivers. The basis for these simulations is the same field of operation and the same algorithm as in the first example. The simulations were carried out using the Fraunhofer IVI simulation model.

If two drivers are equipped with the algorithm and the statistical driver model, 36 configurations of the driver behaviour are possible if the initial values for reaction time and brake intensity are used.

Table 5: possible combinations and dedicated probabilities (double driver)

double driver equipped					
	driver 1		driver 2		
combination	**reaction time [s]**	**brake intensity [%/100]**	**reaction time [s]**	**brake intensity [%/100]**	**probability [%/100]**
1	0.48	0.5	0.48	0.5	0.0146
2	0.48	1.0	0.48	0.5	0.0292
3	0.48	0.5	0.48	1.0	0.0292
4	0.48	1.0	0.48	1.0	0.0438
5	0.48	0.5	0.7	0.5	0.0148
6	0.48	1.0	0.7	0.5	0.0294
7	0.48	0.5	0.7	1.0	0.0298
8	0.48	1.0	0.7	1.0	0.0444
9	0.48	0.5	1.08	0.5	0.0133
10	0,48	1.0	1.08	0.5	0.0279
...	...	...	...	...	...
33	1.08	0.5	1.08	0.5	0.0121
34	1.08	1.0	1.08	0.5	0.0242
35	1.08	0.5	1.08	1.0	0.0242
36	1.08	1.0	1.08	1.0	0.0363
					1

Table 5 shows a cut-out from the whole table for the 36 combinations. Each accident scenario was simulated with all of the 36 combinations to generate the intermediate result. This makes up a resulting dataset of 114,192 possible result files. After these simulations, the statistical variation of the results regarding their probability to occur is carried out in a similar way as in the single driver example. Table 6 shows a cut-out of the basis variation table.

Table 6: statistical variation of simulation results (double driver)

configuration scenario	**1**	**2**	**3**	**4**	**5**	...	**100**
Accident number	combination	combination	combination	combination	combination	combination	
1	34	12	26	35	15	...	1-36
2	6	36	28	22	22	...	1-36
3	1	35	24	8	23	...	1-36
4	32	8	12	4	36	...	1-36
5	6	34	34	15	11	...	1-36
6	9	2	35	16	8	...	1-36
7	9	20	33	30	28	...	1-36
8	3	31	34	31	14	...	1-36
9	8	5	4	32	35	...	1-36
10	14	18	23	17	27	...	1-36
11	30	36	18	10	32	...	1-36
12	7	16	18	26	16	...	1-36
13	15	24	26	30	18	...	1-36
14	18	16	23	28	36	...	1-36
15	35	3	4	7	36	...	1-36
16	22	12	35	28	28	...	1-36
17	6	21	19	19	24	...	1-36
...							
3127							
	result 1	**result 2**	**result 3**	**result 4**	**result 5**	**result ...**	**result 100**
minimal effect of all results							
maximal effect of all results							

Once there are no more significant changes in the overall result borders, the final results can be analysed in a similar way to the first example. This analysis is carried out for the collision speeds and then compared to the first results.

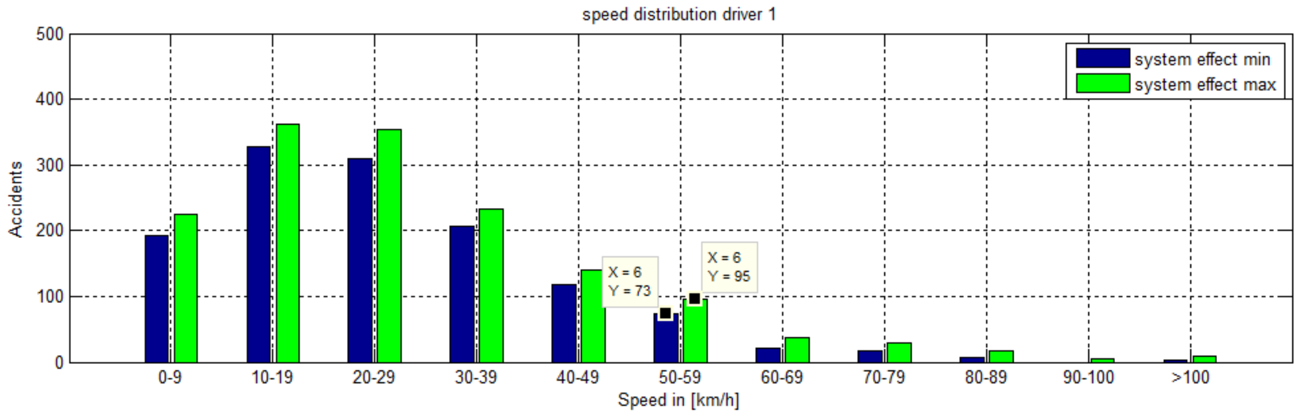

Figure 11: distribution of collision speeds of driver 1 (double driver example)

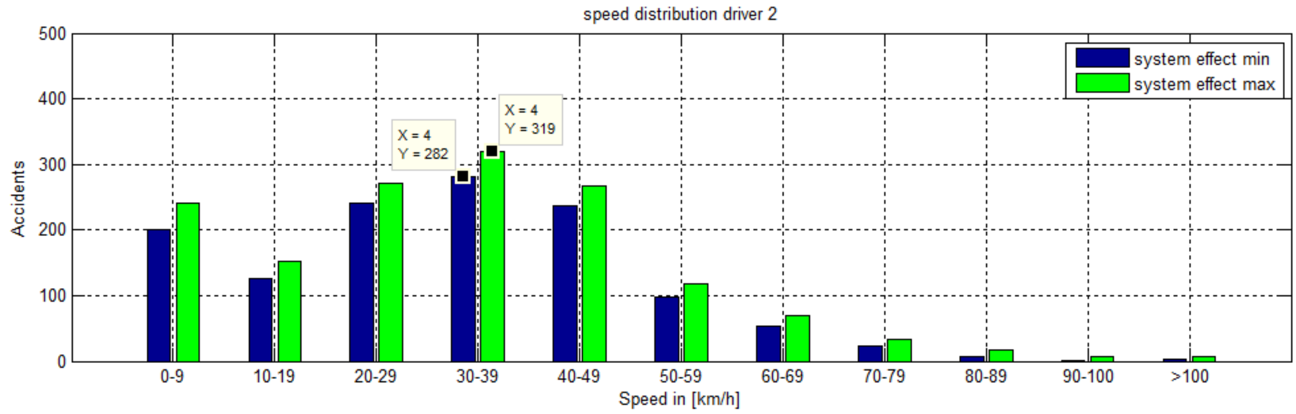

Figure 12: distribution of collision speeds of driver 2 (double driver example)

Figure 11 and 12 show that, in general, the number of accidents can be reduced significantly if both drivers are equipped with the warning system. The comparison with Figure 9 and 10 is shown in Table 7.

Table 7: comparison of single and double driver equipped

	single driver example			double driver example		
	min	**max**	**spread**	**min**	**max**	**spread**
Group 6 (50-59 km/h) driver 1	76	94	**18**	73	95	**22**
Group 4 (30-39 km/h) driver 2	363	378	**15**	282	319	**37**

The comparison in Table 7 shows that the spread of the min and max values is much higher when both drivers are equipped with the statistical driver model, even if the total numbers of accidents is lower. This underlines the necessity of the usage of this statistical driver model to point out the spread or tolerance of the estimated benefit of a warning system.

CONCLUSION

This paper presented a novel method to estimate the benefit of advanced safety systems with a warning functionality. It states important reasons for the necessity of driver models in the benefit estimation by simulation of real world accidents. The paper shows how to create a statistical driver model and its application in accident simulations for one and more drivers which are equipped with warning safety systems. Some representative results are given to underline the importance of tolerances in benefit estimation and accident simulation.

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[4] Christian Erbsmehl, Angela Schubert: “The GIDAS Pre-Crash-Matrix”, 5th ESAR-Conference „Expert Symposium on Accident Research”, Hannover 2012

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The current international tyre regulations cause road accidents

J. Ahlgrimm (D), H. Burg (D), G. Kasanicky (SK), S. Micke (D),

S. Schal (D), H. Steffan (A) and E.C. von Glasner (D)

European Association for Accident Research and Accident Analysis (EVU), Graz, Austria

Abstract - The current Brussels EU Regulation No. 1235/2011, valid from May 30, 2012, has introduced an European Tyre Label with wet grip index G classes from A to G for passenger car tyres C1, light commercial vehicles tyres C2 and heavy truck- and bus tyres C3. Every wet grip class for each vehicle category has a defined band of numerical values for the wet grip index G. The legislated wet grip values G in this EU- Regulation are very low. The measured braking distances and corresponding impact speeds of the test vehicles are showing very critical results.

Regulation No. 1235/2011 of the European Parliament and the Council for Type Approval of Vehicles (EU) should be changed in such a way, that for C1-tyres (normal passenger car~~s~~ tyres) the minimum wet grip index G is 1.25. All C2-tyres (light commercial vehicle~~s~~ tyres) should at least meet a minimum wet grip index of G = 1.1. All C3-tyres (heavy truck~~s~~ and bus~~es~~ tyres) should at least meet a minimum wet grip index of G = 0.95.

Due to the missing lower limits for G in the wet grip class F for C1, C2 and C3 tyres according to Commission Regulation (EU) No. 1235/2011, officially valid from 30 May 2012, a tyre-to-road coefficient of adhesion in the extreme of 0 (zero) is legally permitted. This is an apparent flaw in above cited EU Regulation, which causes a potential danger to the road traffic safety for all motor vehicles in Europe with such tyres. The wet grip class F has to be removed urgently from said EU-Regulation, since a direct liability of the responsible EU-Commission can not be excluded.

1. RETROSPECTIVE VIEW

Before the year 2000 vehicle manufacturers were responsible for the selection of tyres, which were chosen after lengthy and intensive tests and were matched to the vehicles. These tyres were specified in the vehicle registration certificate.

Resulting from a complaints procedure of EU against the Federal Republic of Germany because of “unnecessary business obstructions on the market” codifying of tyre brands as done by the vehicle manufacturers was abandoned from the year 2000 onwards.

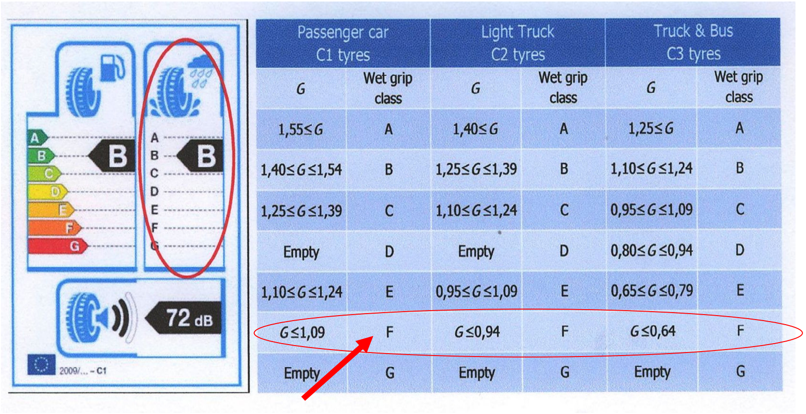
In the following years from 2000-2012 there were no legal demands per EU legislation on the lateral force- or braking force performance of tyres on a wet road surface.

2. DEMANDS OF THE EUROPEAN UNION ON THE BRAKING ABILITY OF TYRES ON WET ROADS

The EU has introduced a tyre label in the year 2012, which includes requirements on the braking ability of tyres on wet roads for passenger cars (C1-tyres), for light trucks (C2-tyres) as well as for heavy trucks and buses (C3-tyres).

These EU-requirements are subdivided again into braking performance classes from A to G classified according to the degree of the wet grip index G, which allows some evidence of the braking and road holding ability of tyres on a wet road surface (**Figure 1**).

Figure 1: EU-Label Demands on Tyres for Cars, Light and Heavy Trucks



Passenger car C1 tyres		Light Truck C2 tyres		Truck & Bus C3 tyres	
G	Wet grip class	G	Wet grip class	G	Wet grip class
1,55≤G	A	1,40≤G	A	1,25≤G	A
1,40≤G≤1,54	B	1,25≤G≤1,39	B	1,10≤G≤1,24	B
1,25≤G≤1,39	C	1,10≤G≤1,24	C	0,95≤G≤1,09	C
Empty	D	Empty	D	0,80≤G≤0,94	D
1,10≤G≤1,24	E	0,95≤G≤1,09	E	0,65≤G≤0,79	E
G≤1,09	F	G≤0,94	F	G≤0,64	F
Empty	G	Empty	G	Empty	G

NOTE: There are no limits set for C1-, C2- and C3-tyres in class F

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This label contains a dangerous mistake:

The minimum legal demands on the wet grip index class F for C1-, C2- und C3-tyres, shown in Figure 1, are absurdly low and they are a great danger for the safety of all traffic participants.

In the current EU-legislation (EU Regulation No. 1235/2011, valid from May 30, 2012), there is even explicitly defined under wet grip index class F with the "≤" definition for C1-, C2- und C3-tyres:

The wet grip index G can be lower than 1,1 (for C1-tyres), lower than 0,95 (for C2-tyres) and lower than 0,65 (for C3-tyres) without limit. That means in the extreme, that tyres with a wet grip index of G=0, which are not able to realise any braking or lateral forces, are legally permitted on the European road system! All it takes to comply with this "EU tyre safety regulation" is a printed, removable sticker of paper attached to the tyre, defining the tyre as "Wet Grip Class F", and even the lowest road-holding quality of tyres qualifies legally for use on the European Market.

It is remarkable, that the "wet grip class", at which the tyre is sold, is not required to be permanently moulded on the tyre sides, which is for example legislated for the winter tyre definition.

2.1 Tests with passenger car tyres (C1-tyres)

Braking tests with C1-tyres available on the market showed significantly, that tyres of the wet grip classes E and F are a safety risk because of the big differences in braking distances (**Figure 2**).

A car with premium tyres of class A showed a braking distance of 32 metres, when braking from 80 km/h on a wet road. A car equipped with budget-tyres of class F, showed a braking distance of 48 metres, which results in an impact speed of 46 km/h into the already standing vehicle with the premium-tyres of class A (**Figure 3**).

If this braking procedure happens on a wet motorway from 130 km/h, the impact speed will increase to more than 70 km/h (**Figure 4**).

Additionally, one has to take into account the serious fact that due to low minimum values for the wet grip index G the effectiveness of driver assistance systems like emergency braking system, lane keeping, vehicle stability control, etc. is reduced significantly, and thus influences negatively the traffic safety.

Figure 2: Comparison of Braking Distances from 80 km/h on a Wet Road

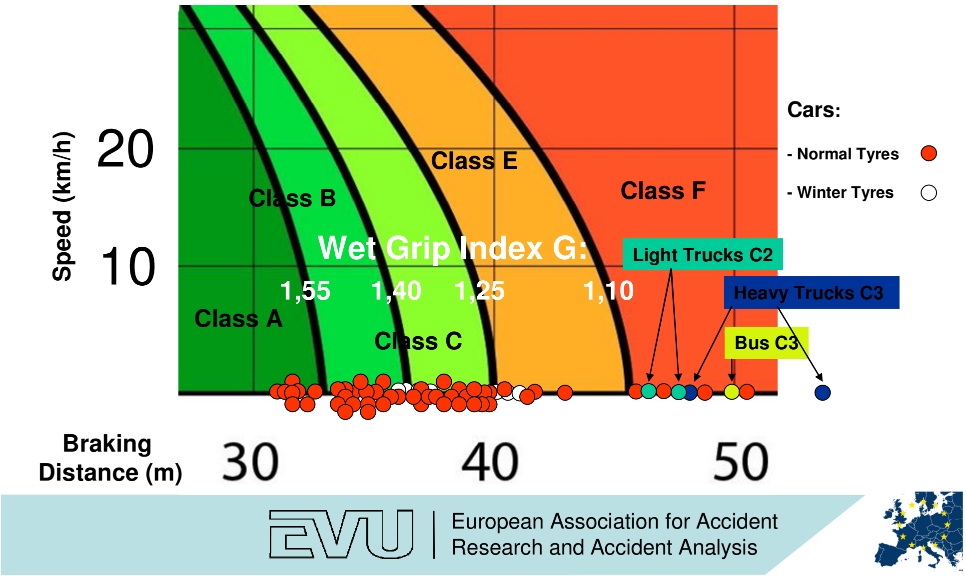

Figure 3: Braking Distances from 80 km/h with Car Tyres of Classes A, E and F

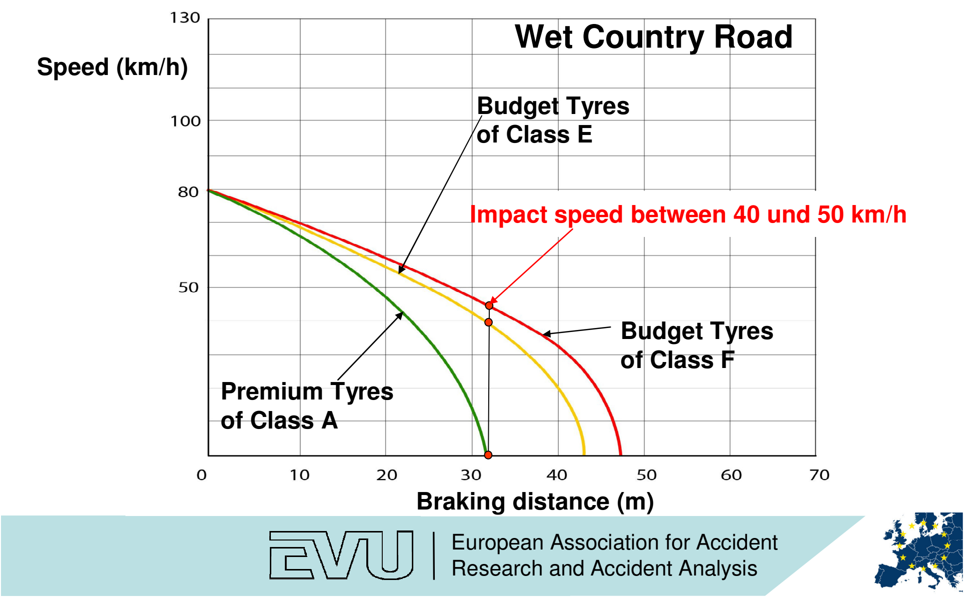

Figure 4: Braking Distances from 130 km/h with Car Tyres of Classes A, E and F

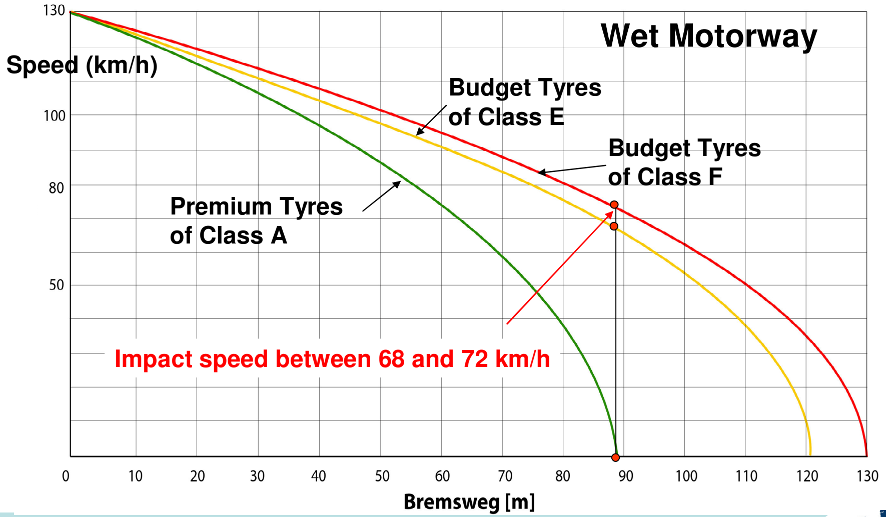

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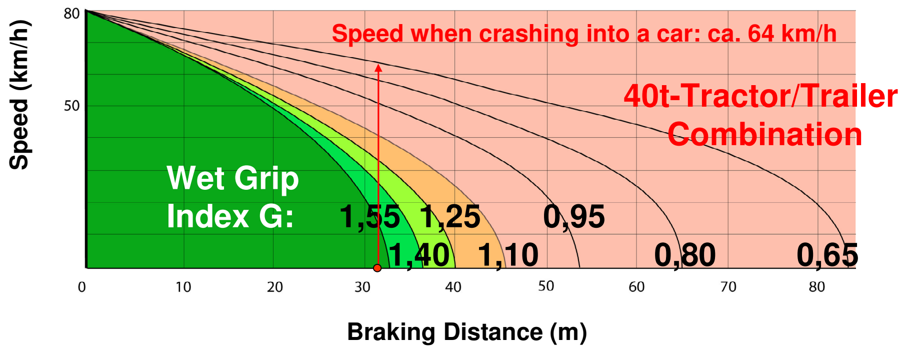
Figure 5: Braking Distances of a Car (C1-Tyres, Class A) and a Tractor/Trailer (C3-Tyres, Class F)



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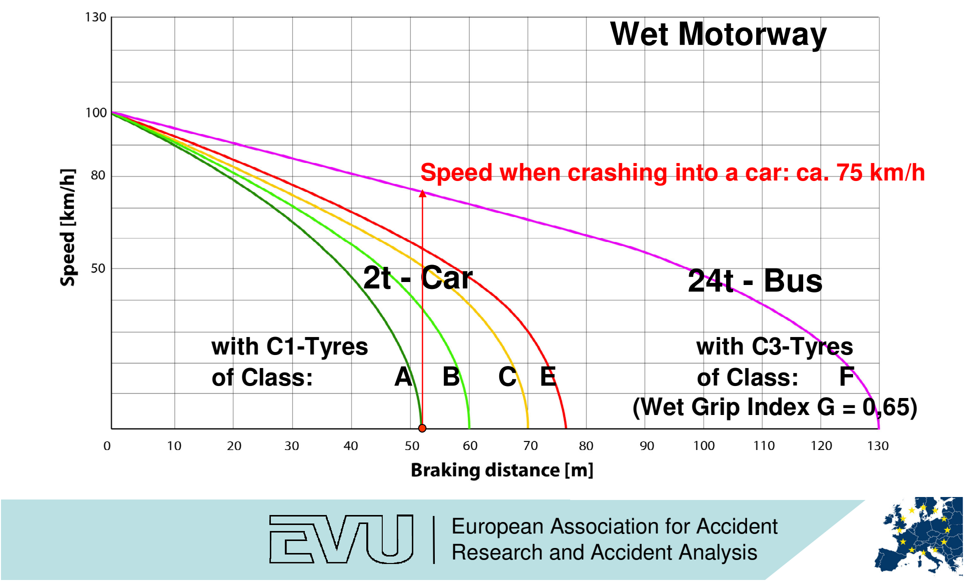
2.2 Investigations of tyres for trucks and buses (C2- und C3-tyres)

Contemplating the EVU-analysis, the wet grip index G = 0,65, as accepted by EU for tyres of heavy trucks and buses, means, that the coefficient of adhesion between tyre and road surface is only k = 0,35. Additional calculations and computer simulations showed, that tyres with a wet grip index of G = 0,65 reached a very long braking distance of ca. 83 metres from 80 km/h only (**Figure 5**).

Figure 6: Braking Distances from 100 km/h with a Car (C1-Tyres) and a Bus (C3-Tyres)



As already shown in chapter 2.1, a car with premium tyres of wet grip index class A needs a braking distance of ca. 32 metres (**Figure 3**). During simultaneous braking in a convoy a heavy truck or a heavy tractor/trailer combination with tyres of a wet grip index G = 0,65, accepted by the EU-regulations, would crash into the already standing passenger car with a speed of ca. 64 km/h (**Figure 5**).

Under the same conditions a bus braking from 100 km/h on a wet motorway would hit the already standing car with a speed of ca. 75 km/h (**Figure 6**).

3. DEMANDS ON THE EUROPEAN LEGISLATION

1. The current low values for the wet grip index class G, as legislated by the European Union, are just contrary to the demand of the same EU to reduce drastically the number of fatally and seriously injured persons on our roads and will not contribute positively to the safety demands in the EU-Action Programme 2011-2020.

2. The regulation No. 1235/2011 of the European Parliament and the Council for Type Approval of vehicles (EU) should be changed in such a way, that for C1-tyres (normal passenger cars) the minimum wet grip index G is 1.25.

3. All C2-tyres (light commercial vehicles) should at least meet a minimum wet grip index of G = 1.1. All C3-tyres (heavy trucks and busses) should at least meet a minimum wet grip index of G = 0.95.

4. All C1-winter tyres should at least meet the demand of the minimum wet grip value G of 1.15. The minimum wet grip value for C2-winter tyres should be 0.95 and for C3-winter tyres it should be 0.85.

5. Due to the missing limits for G in the wet grip class F a tyre-to-road coefficient of adhesion of 0 (zero) is legally permitted, according to Commission Regulation (EU) No. 1235/2011, officially valid from May 30, 2012. Therefore the road traffic safety for motor vehicles in Europe is acutely jeopardized. This is an apparent flaw in above cited regulation and it is strongly recommended, that the wet grip class F is removed urgently from said regulation, since a direct liability of the responsible EU Commission can not be excluded in this case.

Injury Estimation for Advanced Automatic Collision Notification (AACN) in Germany

N Lubbe*, T Kiuchi**

*Toyota Motor Europe NV/SA , Technical Affairs Planning Dept., Hoge Wei 33, 1930 Zaventem, Belgium
**Toyota Motor Corporation, Vehicle Engineering Development Div., 1200, Mishuku, Susono, 410-1193 Japan

Abstract - This study aimed at developing an injury estimation algorithm for AACN technologies for Germany and compared them to findings based on Japanese data.
The data to build and to verify the algorithm was obtained from the German in-depth Accident Database (GIDAS) and split into a training and a validation dataset. Significant input variables and the generalized linear regression model to predict severe injuries (ISS>15) were selected to maximize area under the receiver operating characteristic curve (AUC).
Probit regression with the input parameter *multiple impact, delta v, seatbelt use* and *impact direction* gave the largest AUC of 0.91. Sensitivity of the algorithm was validated at 90% and specificity at 76% for an injury risk threshold of 2%.
It appears that no major differences between Japan and Germany exist for injury estimation based on *delta v* and *impact direction*. However, far side impact and multiple crash events appear to be associated with a larger risk increase in the German data.

INTRODUCTION

Fatalities from road traffic accidents can be reduced by accident avoidance before the collision, mitigation of consequences during a collision and medical treatment after a collision. Automatic Collision Notification (ACN) describes technologies that establish a communication link with rescue services and forward the position of the vehicle given a collision. The rescue services then decide on appropriate action. These technologies are established in US and Europe and know for example as "ecall" [1].

Advanced Automatic Collision Notification (AACN) describes technologies that exceed ACN functionality by estimating injury outcome based on some crash parameters. Medical rescue services have to dispatch the appropriate unit to the accident scene and transport any injured person to the appropriate medical facility. Appropriate hereby means that injury severity and medical treatment need to match: Treating severe injuries at non-specialized facilities (referred to as under triage) increases fatality risk [2] while treating minor injuries at specialized Trauma centers (referred to as over triage) might overload these and might lead to transport times longer than necessary. The information provided by AACN – an estimation of injury severity – aims at aiding medical rescue services to decide on appropriate action. AACN technologies are established in the USA, where for example OnStar is a system introduced on the market by General Motors in 1996 [3]. Most research concerns road traffic accidents in the USA or Japan. In Germany, AACN functionality is offered by BMW as part of "Connected Drive" since 2007. The "Urgency" algorithm was trained on US data to predict risk of severe injury [4]. It is not clear if the insights from research specific to the USA or Japan can be directly applied to Germany or how AACN technologies can be tuned to work effectively in Germany. Brehme et al. [5] developed an injury prediction tool for Germany based on GIDAS data, which was validated by Hannawald et al. [6]. The tool used logistic regression and a priori defined explanatory variables based on visual inspection of the accident scene to estimate the likelihood of single injuries.

This study aims at developing an injury estimation algorithm for AACN technologies for Germany selecting regression model and explanatory variables as a set of crash parameters for best model fit and compared them to findings based on Japanese data [7].

METHODS

Estimation output: A metric for injury severity

Many metrics to quantify injury severity and estimate fatality risk have been developed. There is vast literature on this topic. A thorough review exceeds the scope of this paper.

The metrics Maximum Abbreviated Injury Score (MAIS) [4,8] and Injury Severity Score (ISS) [9-10] are used to characterize injury severity for a patient. AIS and Mortality Risk Ration (MRR) [11] are used to characterize severity on injury level. For this study, the authors adapt findings of the German Trauma Registry. The RISC score [12] is used to estimate chances of fatality for a patient. Hospital performance is judged comparing actual fatality rates with those estimated by RISC. Further quality assessment is based on the time passed for several treatments for severely injured, whereby severely injured is defined by ISS≥16 [13]. As it is unclear for now how to relate RISC levels to appropriate medical care, the algorithm estimates the event of ISS≥16 and thereby the need for treatment in a specialized Trauma Center.

Estimation input: Variables characterizing crash severity and vulnerability

For the USA, it was recommended to primarily make use of

- Delta v
- Principal direction of Force (PDOF)
- Seatbelt use
- Crash with multiple impact
- Vehicle type

If contact with the occupant is possible, occupant age should also be used to estimate risk of having a severe injury (ISS>15) [9]. These input variables with an addition of occupant gender were used in the injury estimation model by Kononen et al. [10]. Yoshida et al. [7] used delta v and PDOF in a “base model” and added seatbelt use, multiple impact and occupant age in a “full model”.

For this study, all the above mentioned variables were pooled with other variables as candidates for the injury estimation algorithm. Delta v and PDOF were taken from the collision that caused the largest damage to the vehicle. Further variables that potentially can estimate injury outcome were:

- Roll-over event [yes / no]
- Occupant height [cm], weight [kg], age [years] and gender
- Vehicle registration [calendar year]

Candidates were selected based on their expected contribution on injury outcome and their expected availability in the near future. For example, the authors expect occupant characteristics (height, weight age, gender) to influence injury outcome and to be available in the future through personalized car communication. Other variables, such as occupant position, collision partner, or structural engagement were not expected to be available in the near future and thus not included.

The final input variables were determined by backward selection in several estimation models as described in the next section. That means, starting from a given set of variables the one with the highest p-value was removed until all p-values were below 0.1. Amongst the set of variables fulfilling the above condition, the final model was selected based on largest area under the receiver operating characteristic curve (AUC). AUC gives an overall measure of estimation accuracy, with a value of one representing perfect accuracy [14].

Estimation model: Linking input and output

Generalized linear regression models were used to relate injury risk R to input parameter X. Besides the popular logit [4,7,8,10] of the form *Log(R/(1-R))=Xb*, also probit *Norminv(R)=Xb*, and complementary log-log: *log(-log(1-R))=Xb* were modeled. Calculations were performed with Matlab R2013a using glmfit function.

Sensitivity was calculated as the proportion of individuals with the outcome that are correctly classified: True positive / (true positive + false negative). Specificity was calculated as the proportion of individuals without the outcome that were correctly classified: True negative / (true negative + false positive). False positive rate was calculated as the proportion of given alarms that were false: False positive / (false positive + true positive). Similarly, false negative rate was calculated: False negative / (false negative + true negative).

Threshold optimization: Binary response from estimated injury risk

The regression model gives the probability of severe injury between 0% and 100%. A threshold for the decision transport to Trauma Center can be set arbitrarily (for example at 20% [9]) or chosen to minimize overtriage and undertriage [8]. In this study, the transport threshold was obtained through analysis of ROC. The distance of any point of the ROC to the target point was calculated. The distance depends on the injury threshold and is known. The threshold with largest distance to the target was selected. The target was 10% undertriage (1-sensitivity) and 50% overtriage (specificity). These values are recommended in the German Whitebook Medical Care of the Severely Injured [15].

Dataset

The data to build and to verify the algorithm was obtained from the German in-depth Accident Database (GIDAS). GIDAS cases are sampled to be representative for Germany but tend to be biased to higher injury severity [16]. The data used for this study was approximately representative for the injury severity in Germany: National data 2003-2012 for injured passenger car occupants (police reported) recorded fatal injuries in 1.1% of all cases, severe injuries in 14% and slight injury in 85% [17]. The GIDAS dataset for this study contained 1.7% fatal injuries and 19% severe injuries using the same police reported definitions. No weighting factors were applied.

Complete cases from the years 2003-2012 were filtered for front seat occupants >15years in passenger cars and vehicle registration later than year 2000. Each front seat occupant was treated as a separate case. The data was split into a training dataset (to build the algorithm) with uneven case numbers (n=1942) and a validation dataset (even case numbers, n=2048). Some characteristics of the datasets are given in table 1. There was no obvious difference between the sets. For backward model selection, omission of incomplete data was done specifically for each model, depending on the included variables. This means that the number of data differs between models.

Table 1: Characteristics of training and validation data

Variable		Training data	Validation data
Injury outcome	ISS>15	52 (3%)	41 (2%)
	ISS<15	1795 (92%)	1894 (93%)
	ISS unknown	95 (5%)	113 (6%)
DV	Mean	22.2 km/h	22.8 km/h
	SD	15.4 km/h	15.3 km/h
Impact direction	Front	984 (51%)	1067 (52%)
	Near Side	250 (13%)	255 (13%)
	Far Side	191 (10%)	174 (9%)
Belt use		1751 (96%)	1843 (95%)
Occupant age	mean	41 years	42 years
	SD	16 years	17 years

RESULTS

The largest AUC resulted from a probit model with the input parameter *multiple impact, delta v, seatbelt use* and *impact direction.* AUC was 0.908. Best fit model specifications (regression coefficients b, standard error of coefficients and p-value of coefficients) are given in Table 2. The ROC curve is depicted in figure 1. Sensitivity, specificity, false positive rate and false negative rate are depicted in figure 2. Best sensitivity (92%) and specificity (75%) was reached at a threshold of R = 2%.

Table 2: Best fit model specification

Parameter	Unit	b	SE	p-value
Intercept	-	-2.912	0.297	<0.001
Multi impact	Yes = 1, No = 0	0.375	0.157	0.0169
Delta v	Km/h	0.040	0.004	<0.001
Seatbelt use	Use = 1, No use = 0	-0.708	0.238	0.0029
Impact direction	Near side = 1, other = 0	0.512	0.225	0.0231
	Far side = 1, other = 0	0.923	0.208	<0.001
	Front	-	-	-
	Rear	-	-	-

Figure 3 illustrates the regression results. Severe injury risk for a single belted front or rear impact was 5% at a delta v of 50 km/h. When unbelted, the risk more than tripled to 18%. A belted near side impact at delta v of 50 km/h lead to a risk of severe injury of 13%.

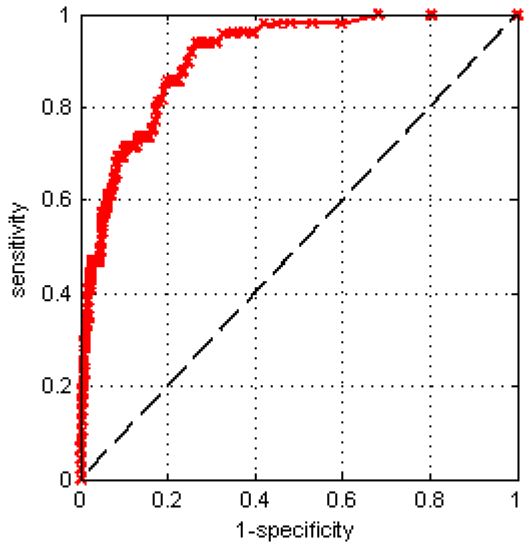


Figure 1: ROC curve of best fit model

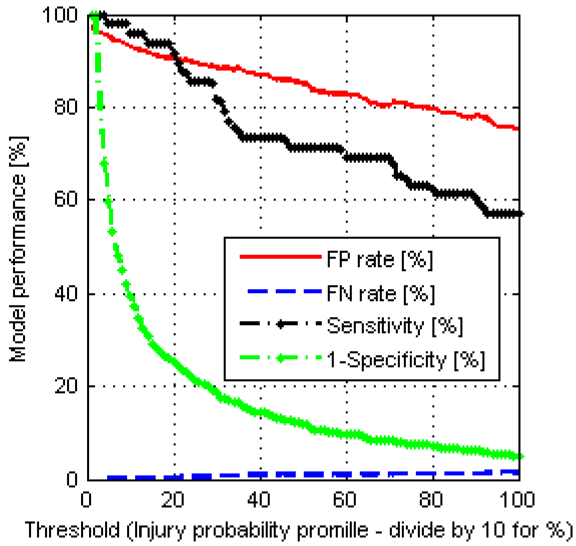


Figure 2: Characteristics of best fit model

The probit model with specifications as given in Table 2 and a threshold for estimating injury of R≥2% was validated against the GIDAS validation dataset. Sensitivity was 90% (target: ≥90%), specificity was 76% (target: ≥50%), false positive rate was 92%, and false negative rate was 0.3%.

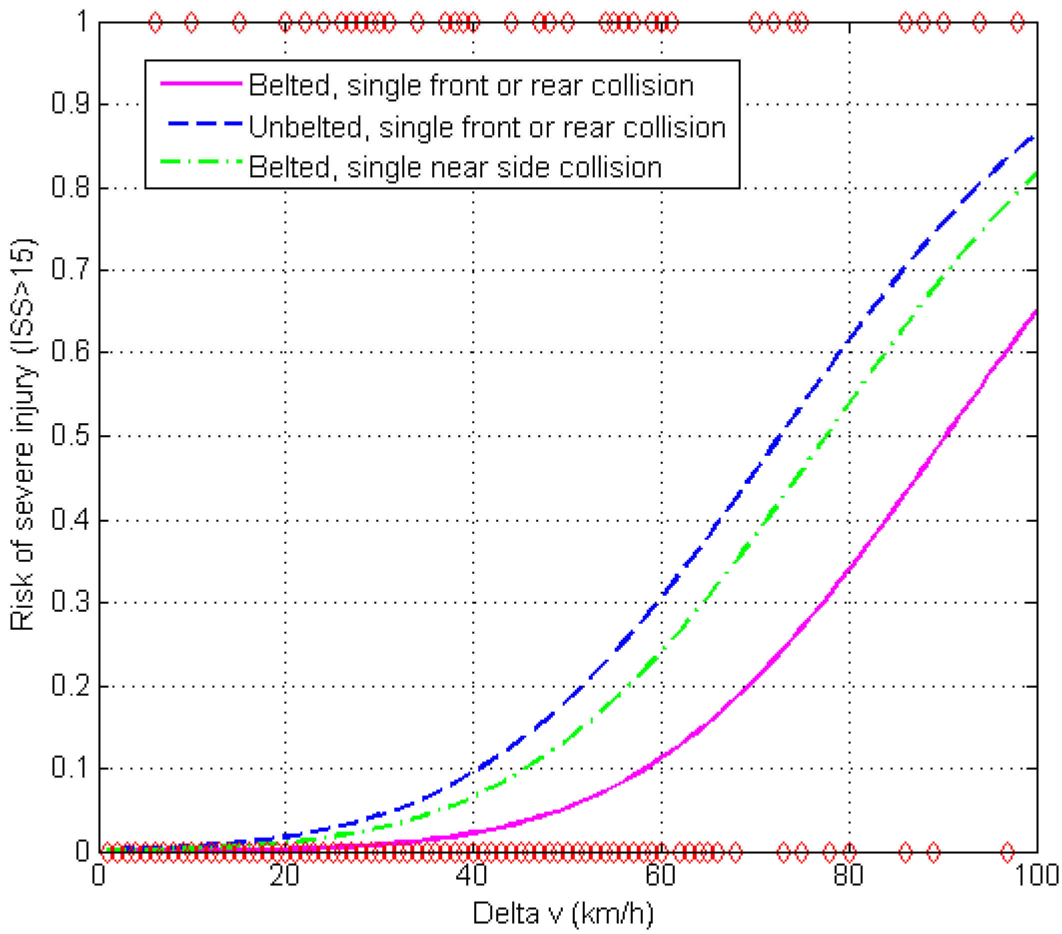


Figure 3: Best fit model injury risk curves

DISCUSSION

There is some indication that far side accidents were associated with a higher probability of severe injuries than near side accidents. In contrast, crash mechanics imply that, due to intrusion and contact injuries, near side impacts are more likely to lead to severe injury than far side impacts. The difference in probability in this study was statistically not significant and therefore might be coincidence. Alternatively, the difference might be due to a high share of cars equipped with advanced near side impact protection, such side airbags (59% of vehicles equipped) which were shown to reduce injuries [18]. Furthermore, results might be confounded with impact angles. In the training dataset of this study, far side impacts occurred more often angled towards the front.

Table 3 summarizes the ten injury estimation models with largest AUC. Number of data points used (#) and severe injuries in the set (# ISS>15) are also given. The type of generalized linear regression model appears to have only marginal influence on result. The top scoring estimation model contained the same variables independent of regression model. Multiple impact ("Multi"), delta v ("DV"), seatbelt use ("SB"), and impact direction (near side impact: "Near", far side impact: "Far" were the most commonly found estimator variables. Roll-over event ("Roll") and vehicle type ("Van" and passenger car ("Pas")) were included in the models ranking 7-10. Differences due to logit, probit or complementary log-log model appear to be of little importance for estimator variable selection and AUC. It can be noted that risk curves did merely differ for risks below 50% as illustrated in figure 4. However, there was no reason not to benefit from the slightly better performance of the probit model, thus probit was proposed and not the commonly used logit.

Table 3: Top ten injury estimation models according to AUC

Model	variables						AUC	#	# ISS>15
Probit	Multi	DV	SB	Near	Far		0.908038	1719	49
Logit	Multi	DV	SB	Near	Far		0.907002	1719	49
c-loglog	Multi	DV	SB	Near	Far		0.906495	1719	49
c-loglog	Multi	DV	SB	Far			0.9054091	1719	49
Logit	Multi	DV	SB	Far			0.90526	1719	49
Probit	Multi	DV	SB	Far			0.905214	1719	49
c-loglog	Multi	DV	SB	Near	Far	Van	0.9038293	1662	46
c-loglog	Multi	DV	SB	Near	Far	Pas	0.9036431	1662	46
Probit	Roll	DV	SB	Near	Far		0.903423	1717	49
Logit	Roll	DV	SB	Near	Far		0.902209	1717	49

Table 4 displays model characteristics for other input variables. Model 1 and model 2 were developed from Japanese data (n=5 090 980) [7] where all variables were significant in logistic regression to estimate police classified injury outcome (severe and fatal injury versus slight and no injury). Model 3 was developed from US data (NASS CDS, n = 14 673) where all variables except vehicle type were significant in logistic regression to estimate ISS>15 versus ISS<15 injury outcome [10]. Note that regression coefficients were computed from the training dataset of this study and not taken from literature.

The model proposed in this study met targeted specificity and sensitivity. This performance can be compared to the injury estimation model 1 to 2 from the literature, using the given parameter and coefficients. Model 3 cannot be compared directly, as parameters are given on vehicle level, not occupant level. In a first step, the threshold was calculated from the training data to maximize positive distance to the target. In a second step, the performance was calculated with the validation dataset

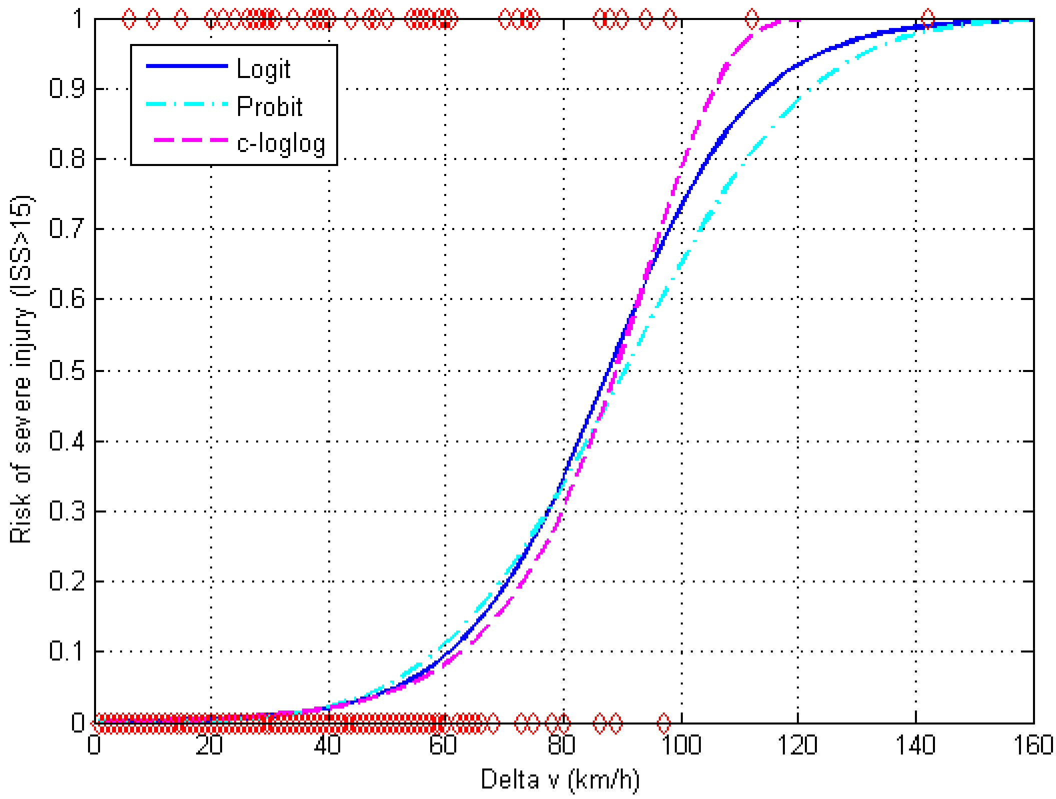


Figure 4: Injury risk curves from logit, probit and complementary log-log regression

Table 4: Model characteristics for alternative input variable selection

Model	Input variables	AUC	#
This study	Multiple Impact, Delta v, Near Side, Far Side, Belt use	0.9080	1719
1(Logit)	Delta v, Front*, Near Side, Far Side	0.8910	1801
2(Logit)	Multiple Impact, Delta v, Front*, Near Side*, Far Side, Belt use, Age*	0.9067	1706
3(Logit)	Multiple Impact, Delta v, Front*, Near Side*, Far Side, Belt use, Age*, Gender*, Vehicle type	0.9041	1647

* not significant at p<0.1

Performance is given in table 5. The "base model" from Yoshida et al. (2012) exceeded targeted specificity and sensitivity. Sensitivity, false positive and false negative rate were comparable to the model developed in this study but specificity was 14% lower.

Using GIDAS data, one or several of the input variables were not significant. A real difference between US, Japan and Germany for injury outcome might be the underlying reason. Insignificant results could also be due to lower case numbers in this study while there is no difference in injury outcome explanation between the countries. The performance of the estimation models from literature with respect to AUC were similar to the best rated ones in this study besides use of non-significant estimator variables. However, the authors believe that the chance of estimating injury outcome based on non-existing relationships is high when using non-significant variables, thus the model in this study was chosen to only contain significant variables.

The injury threshold to decide on transport to a Trauma Center is well below the recommendation of the Recommendations from the Expert Panel of 20% [9]. It might be more meaningful to determine target sensitivity and specificity according to medical, political and other considerations and to compute an appropriate threshold than to set a threshold arbitrarily and to deal with sensitivity and specificity as model outcome.

It appears that no major differences between Japan and Germany exist for severe injury estimation based on delta v and impact direction. The "full model" performance was lower, indicating that the influence of the additional variables might differ between the data from Japan and Germany. When comparing the coefficients for a logistic regression in the variable formulation of Yoshida et al. [7], Table 6 shows differences between the original regression coefficients calculated on the Japanese data and the ones calculated on the German data based on the training dataset for crash direction far side (base model, significant at p<0.1) and multiple crash (full model, significant at p<0.05). Statistical significance of difference in coefficients was calculated with a two-sided independent sample t-test. One must keep in mind though that the German data fit predicts ISS>15 injury while the Japanese data fit predicts police reported severe injury.

Table 5: Comparative performance of injury estimation models

	Best fit model (this study)	Yoshida et al. (2012) "base"	Yoshida et al. (2012) "full"	Target
Threshold	2%	1.3%	1.3%	-
Sensitivity	90%	92%	82%	≥90%
Specificity	76%	62%	66%	≥50%
False positive rate	92%	93%	94%	-
False negative rate	0.3%	0.4%	0.8%	-
Number of TN	1332	1105	1120	-
Number of TP	35	48	40	-
Number of FN	4	4	9	-
Number of FP	422	690	583	-

Bose et al. [19] pointed out two limitations of regression models used in literature: The inability to capture non-linear effects and the lack of interaction terms. These limitations exist in this study as well. Interaction terms might improve accuracy, but the dataset was deemed too small for meaningful modelling. Modelling of interaction terms and non-linear effects requires future work on a larger dataset. Survival analysis can make use of censoring information in time to failure analyses. One could formulate the injury estimation model as survival regression with for example delta v as "time" variable and other variables as confounders. This would account for delta v not being exact, i.e. a sustained injury might also have been sustained at a lower speed. Survival regression would yield results for the data at hand. But delta v differs from time in one important aspect: Time to failure is a cumulative measure, which means time is gradually increased until failure is reached while delta v is a singular input (dose). Outcome (response) is likely to differ between a single input and cumulative input: Injury might be sustained at lower delta v if collisions are repeated at ever increasing delta v compared to a single collision at a specific delta v. Thus, it is questionable whether survival regression is applicable for the injury estimation model. Non-linear methods should be explored in the future.

As an alternative to backward selection, Akaike Information Criterion (AIC) can be computed on any combination of predictor variables. AIC consists of a term indicating how well the data fits to the model and a penalty term for the number of model variables:
*AIC = -2 * Log likelihood + 2 * (Number of estimator variables)*

For model selection based on AIC, all data with missing information for at least one variable needs to be omitted to keep a constant dataset across models. This would lead to 1104 cases in the training data with 18 cases of ISS>15. Over fitting was likely to be an issue and model selection based on AIC was ruled out for this study.

Table 6: Regression coefficients for Japanese data fit and German data fit

		Base model	German data	SE	Full model	German data	SE
Intercept		-5.326	-5.421	0.541	-4.129	-4.343	0.736
Delta v	<30	-					
	31-40	2.161	1.921	0.453	2.052	1.892	0.472
	41-50	2.99	2.426	0.503	2.858	2.384	0.533
	51-60	3,467	3.480	0.489	3.310	3.509	0.52
	>60	4.175	4.547	0.509	3.995	4.645	0.523
Crash direction	Front	0.257	0.151*	0.576	0.163	0.038*	0.59
	Near side	1.524	1.120	0.659	1.446	1.080*	0.674
	Far side	**1.082**	**2.143**	0.605	0.984	1.890	0.635
	Rear	-					
Belt use	Yes				-1.371	-1.519	0.47
	No						
Multiple crash	Yes				***0.099***	***0.784***	0.328
	No						
Occupant age	<54						
	55-64				0.477	-0.605*	0.66
	>65				0.812	0.413*	0.439

*not significant at p<0.1; Significant differences between Japanese and German fit coefficients at p<0.1 in bold, significant differences at p<0.05 in italic and bold

CONCLUSION

An algorithm to estimate severe injury (ISS>15) for front seat passenger car occupants older than 15years was developed and validated based on GIDAS data. The model with significant input variables and the best estimation results (largest AUC) was found to make use of information about delta v, multiple impact, seatbelt use, and crash direction: Far side and near side impact. Injuries in front and rear-end collisions can be estimated, but did not require a specific regression coefficient. A probit model is proposed, but logit or complementary log-log regressions gave similar results. Sensitivity was 90% and specificity was 76%, meeting target performance.

The "base model" developed by Yoshida et al. [7] for injury estimation in Japan showed a comparable performance using delta v and crash direction information. It appears that no major differences exist for injury estimation in Japan and Germany based on these variables. However, far side impact and multiple crash events appear to be associated with a larger risk increase in the German data. Further research is required to investigate these differences, and to validate the model and estimator selection proposed in this study with a larger dataset.

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Characteristics of Crash Data from Event Data Recorders in Collisions with Narrow Objects

Ryo Oga*, Nobuaki Takubo*, Kenshiro Kato*, Takaaki Terashima*

*National Research Institute of Police Science, 6-3-1 Kashiwanoha, Kashiwa-shi, Chiba, Japan

Abstract - Event data recorders (EDRs) are a valuable tool for in-depth investigation of traffic accidents. EDRs are installed on the airbag control module (ACM) to record vehicle and occupant information before, during, and after a crash event. This study evaluates EDR characteristics and aims to better understand EDR performance for the improvement of accident reconstruction with more reliable and accurate information regarding accidents. The analysis in this report is based on six crash tests with corresponding EDR datasets.

INTRODUCTION

Event data recorders (EDRs) are a valuable tool for in-depth investigation of traffic accidents. EDRs are installed on the airbag control modules (ACM) to record vehicle and occupant information in the brief time before, during, and after a crash event.

In January 2008, the US National Highway Traffic Safety Administration published their revised final rules regarding EDRs [1]. In March 2008, the Japanese Ministry of Land, Infrastructure, Transport and Tourism finalised the technical requirements for EDR use in light vehicles, defined as vehicles with a gross vehicle weight rating of 3500 kg or less [2]. This rule is comparable to a similar US regulation (49 CFR Part 563) [3]. EDRs are now being installed in ACMs by several automakers in Japan.

EDRs generally record indicated vehicle speed, engine speed, engine throttle or accelerator pedal state, and the state of service brakes before the crash event. Furthermore, delta-V is recorded during crash events. EDRs are thus promising for traffic accident investigations.

However, it is necessary to examine the reliability and accuracy of EDR data. The aim of this study is to evaluate EDR characteristics and to understand EDR performance for the improvement of traffic accident investigations. This study focuses on EDR crash data on collision with narrow objects, real car crash tests were performed to evaluate the resulting data.

EXPERIMENTAL PROCEDURE

General Description of Analysis Method

Crash test data are used for EDR data comparison. As shown in Figure 1, accelerometers with a 10 kHz sampling rate were attached to the cars. The acceleration data obtained from the sensors are integrated to obtain delta-V, the velocity change during the collision. Vehicle crash behaviours were captured by high-speed video cameras. An external optical speed sensor is used to obtain vehicle impact velocities.

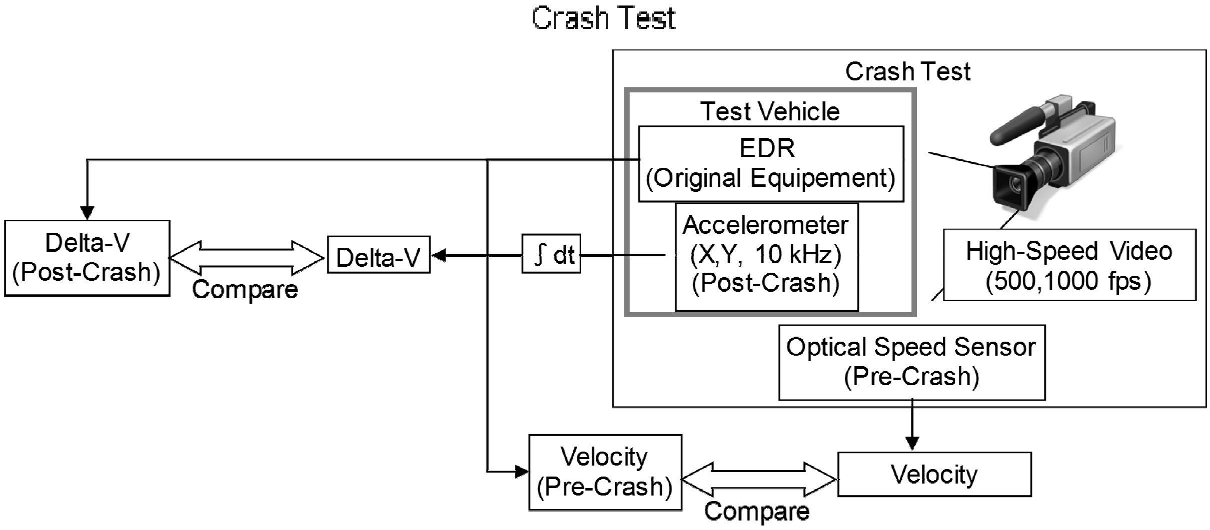

Figure 1 Analysis method in crash tests

Pre-crash velocity recorded by each EDR (V_{EDR}) was compared with data from an optical speed sensor (V_{op}). Post-crash maximum delta-V and delta-V versus time history EDR data were compared with the data calculated using ACM accelerometers (A-EDR) and data from high-speed video cameras (Video). Where A-EDRs were not available, data from accelerators on the centre of the car floor were used.

Crash Tests Conditions

Typical real-world accidents such as a single-car collision against a road-side object were simulated in crash tests. As Figure 2 shows, six crash tests were performed to evaluate the EDR data. Toyota Corollas were used as test vehicles. The test vehicles were equipped with ACMs at the centre floor in front of the shift lever box under the centre console. After crash tests, the ACMs were removed for downloading the EDR data. Details of each test condition are below.

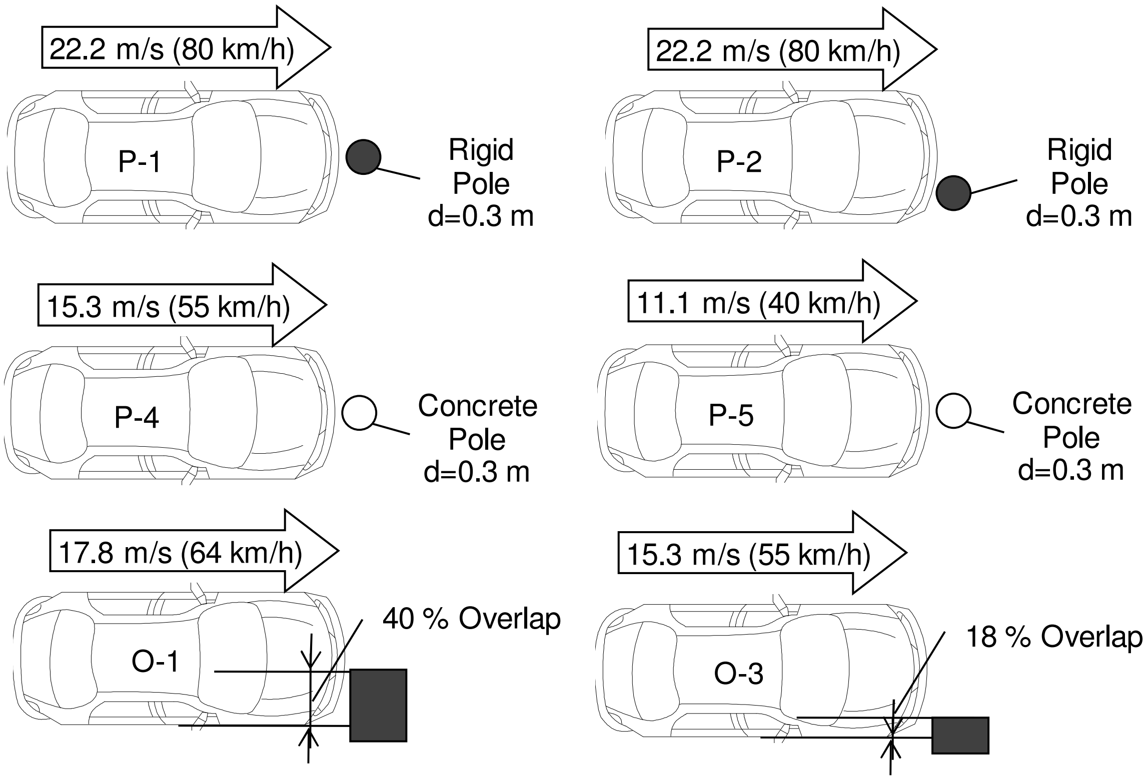

Figure 2 Conditions for the six crash tests

Car to rigid pole frontal centre collision (P-1)

Test vehicle P-1 was a Toyota Corolla with front, side, and curtain airbags. The impact speed was 22.2 m/s (80 km/h). The pole was a steel pipe filled with concrete. The pole diameter was 0.3 m, which is a common size for electric utility poles in Japan. The front centre of the test vehicle collided against the pole.

Car to rigid pole frontal offset collision (P-2)

Test vehicle P-2 was a Toyota Corolla with front, side, and curtain airbags. The impact speed was 22.2 m/s (80 km/h). The pole was a steel pipe filled with concrete. The pole diameter was 0.3 m. The test vehicle's right front side member collided against the pole (offset 460 mm).

Car to concrete pole collision at high speed (P-4)

Test vehicle P-4 was a Toyota Corolla with front, side, and curtain airbags. The impact speed was 15.3 m/s (55 km/h). A concrete pole was used to model the type of electric utility pole common in Japan. The pole diameter was 0.3 m. The front centre of the test vehicle collided against the pole.

Car to concrete pole collision at low impact speed (P-5)

Test vehicle P-5 was a Toyota Corolla with front, side, and curtain airbags. The impact speed was 11.1 m/s (40 km/h). A concrete pole was used to model the type of electric utility pole common in Japan. The pole diameter was 0.3 m. The front centre of the test vehicle collided against the pole.

Car to rigid barrier offset collision (O-1)

Test vehicle O-1 was a Toyota Corolla with front, side, and curtain airbags. The impact speed was 17.8 m/s (64 km/h). The test condition was a 40% overlap on the right side against a rigid barrier.

Car to rigid barrier sideswipe (O-3)

Test vehicle O-3 was a Toyota Corolla with front, side, and curtain airbags. The impact speed was 15.3 m/s (55 km/h). The test condition was an 18% overlap on the right side (beyond the front side member) against a rigid barrier.

RESULTS

Test Vehicle Conditions

Figure 3 shows high-speed video images and photographs of the test vehicles. The left column in the figure shows high-speed video images of the test at the maximum deformation with a time counter at the top right of the images. The centre column in the figure shows positions of the test vehicle after collision. The right column in the figure shows deformation of the test vehicles. Time zero is defined at contact of the front bumper against a pole or a barrier. Test observations are described in detail below.

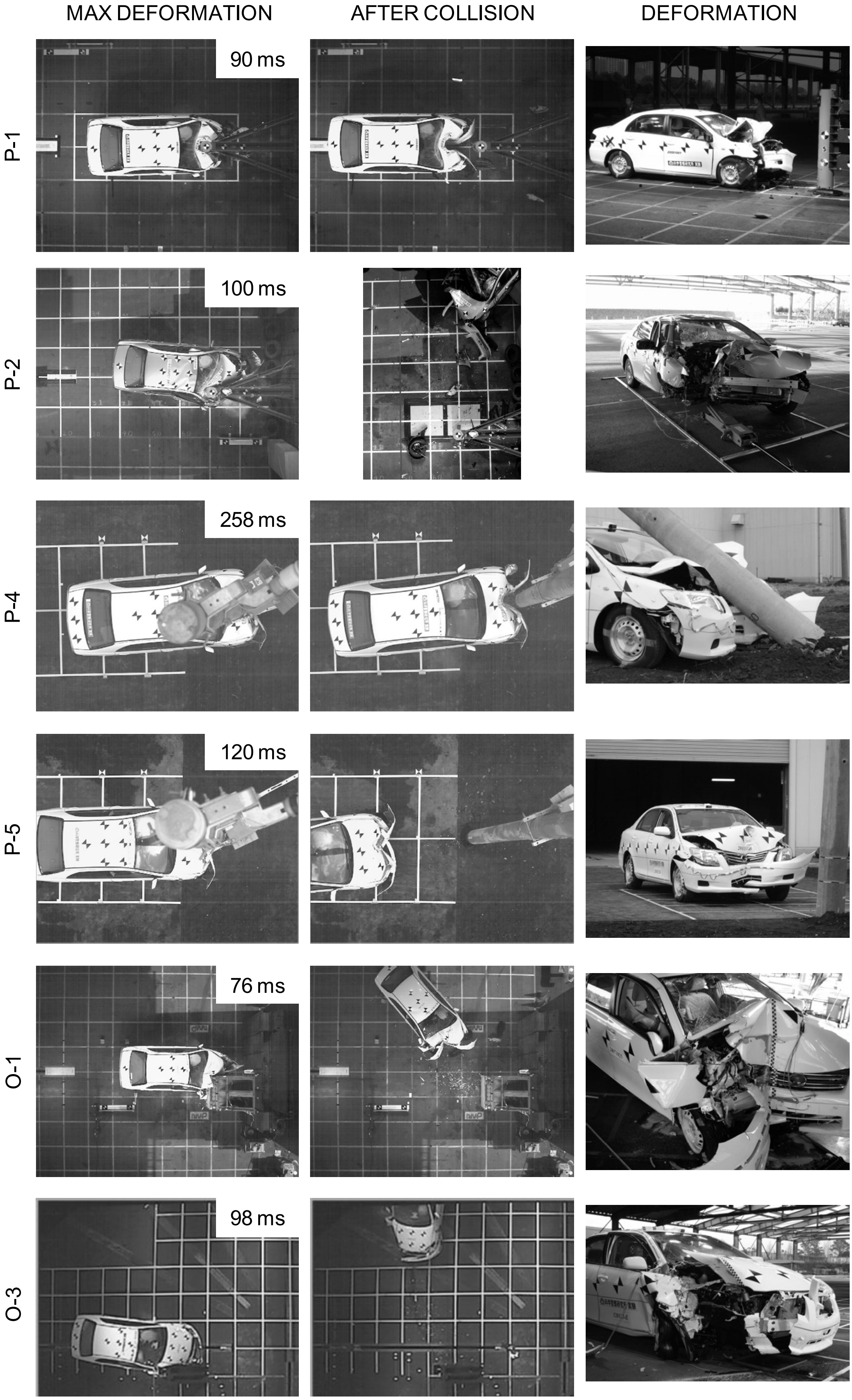

Figure 3 High-speed camera and photographic images

Car to rigid pole frontal centre collision (P-1)

After the collision, P-1 rebounded approximately 1.5 m from the pole. The front airbags deployed at the instant of the collision. The lateral accelerometers did not detect the impact, so the side and curtain airbags did not deploy. The pole dented the centre of the engine room. The maximum deformation was approximately 1.1 m. The side members were bent on the inside.

Car to rigid pole frontal offset collision (P-2)

After the collision, P-2 rotated approximately 135° clockwise, and moved left approximately 5.5 m. The front airbags deployed at the instant of the collision. The lateral accelerometers did not detect the impact, so the side and curtain airbags did not deploy. The right side member was crumpled. The right wheel drive axel was broken. The maximum deformation was approximately 1.2 m. The left side member was bent on the inside.

Car to concrete pole collision at high speed (P-4)

After the collision, P-4 ran approximately 1.0 m over the base of the pole. The front airbags deployed at the instant of the collision. The lateral accelerometers did not detect the impact, so the side and curtain airbags did not deploy. The pole dented the centre of the engine room approximately 0.57 m. The pole broke at ground level, and slowly leaned onto P-4 after the collision.

Car to concrete pole collision at low impact speed (P-5)

After the collision, P-5 rebounded approximately 2.4 m. The front airbags deployed at the instant of the collision. The lateral accelerometers detected the impact, but the side and curtain airbags did not deploy. The pole dented the centre of the engine room approximately 0.42 m. The pole base receded approximately 0.17 m. The pole did not break, but its surface cracked.

Car to rigid barrier offset collision (O-1)

After the collision, O-1 rotated approximately 45° clockwise, and rebounded approximately 2.0 m from the barrier. The front airbags deployed at the instant of the collision. The lateral accelerometers did not detect the impact, so the side and curtain airbags did not deploy. The vehicle deformation was approximately 0.8 m. The bumper reinforcement and the right-front side member crumpled.

Car to rigid barrier sideswipe (O-3)

After the collision, O-3 rotated approximately 90°clockwise, and moved approximately 4.5 m from the barrier. The front airbags deployed at the instant of the collision. The lateral accelerometers detected the impact, but the side and curtain airbags did not deploy. The vehicle deformation was approximately 1.12 m. There was no damage to the front side member. The front right tire and the suspension were broken.

Pre-Crash Data from EDRs

EDRs recorded the vehicle impact speed, and the recorded speed was compared with data from the optical speed meter in Table 1. In all tests, airbag accelerometers sensed an impact shock. In particular, O-3 sensed the impact shock despite there being no deformation of the G sensor–equipped side member. The absolute differences between the EDR impact velocities (V_{EDR}) and those obtained from the optical speed sensors (V_{OP}) were less than 1 m/s.

Table 1 Comparison results of pre-crash impact velocities in the tests

Vehicle	Target	Impact Point	V_{OP}	V_{EDR}	Difference	
			m/s	m/s	m/s	%
P-1	Rigid Pole	Centre	22.4	22.8	0.4	1.8
P-2	Rigid Pole	Right	22.2	22.2	0	0
P-4	Concrete Pole	Centre	15.3	15.6	0.3	2.0
P-5	Concrete Pole	Centre	11.2	11.1	–0.1	–0.9
O-1	Rigid Barrier	40% Overlap	17.9	17.8	–0.1	–0.6
O-3	Rigid Barrier	18% Overlap	15.4	15.6	0.2	1.3

Post-Crash Data from EDRs

EDRs record the max delta-V and time history curve of the delta-V by 200 ms. The maximum delta-V are compared with the data calculated with A-EDR in Table 2. Time history curves for the longitudinal direction are shown in Figure 4 with values calculated using A-EDR and high-speed videos.

Table 2 Comparison results of post-crash maximum delta-V in the tests

Vehicle	Target	Impact Point	Max delta-$V_{A\text{-}EDR}$	Max delta-V_{EDR}	Difference	
			m/s	m/s	m/s	%
P-1	Rigid Pole	Centre	25.0*	17.5	–7.5	–30.0
P-2	Rigid Pole	Right	22.5	20.9	–1.6	–7.1
P-4	Concrete Pole	Centre	12.6	11.7	–0.9	–7.1
P-5	Concrete Pole	Centre	12.2	14.5	2.3	18.9
O-1	Rigid Barrier	40% Overlap	17.4	20.2	2.8	16.1
O-3	Rigid Barrier	18% Overlap	16.5	15.1	–1.4	–8.5

*Data calculated using an accelerometer at the centre of the rear seat.

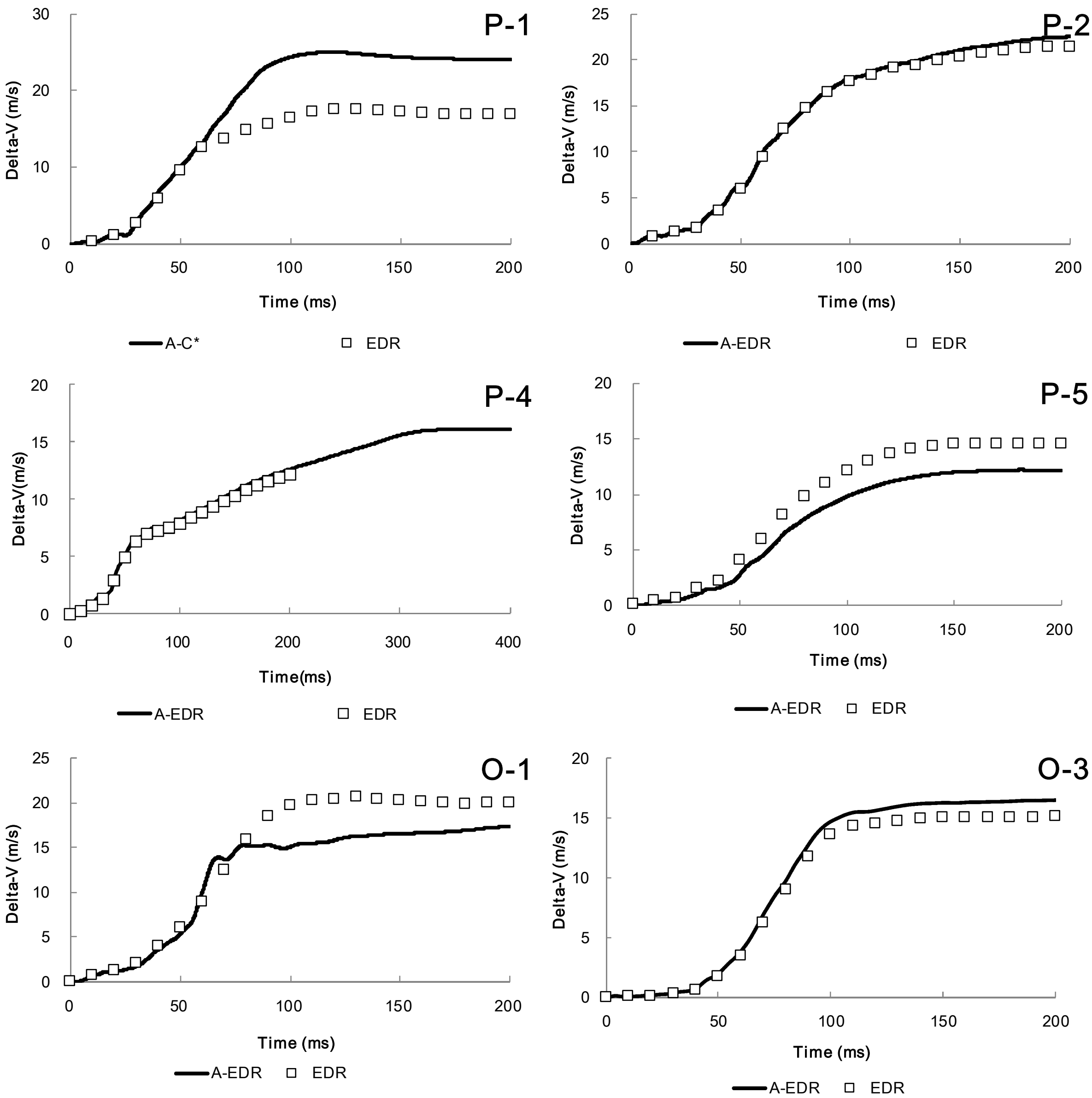

Figure 4 Time history curves of delta-V

*Data calculated using an accelerometer at the centre of the rear seat.

DISCUSSION

Comparison of EDR-recorded pre-crash velocity with the results from an optical speed sensor indicates that the EDR pre-crash velocities were very accurate. The pre-crash speed data were not affected by collision type. EDRs detected impact with two accelerometers (satellite sensors) installed on side members (Figure 5). After a detected impact, longitudinal delta-V is calculated using data from ACM accelerometers.

It was easy for P-2 and O-2 to detect the impact, because the impact point was near the satellite sensor. For P-1, P-4, and P-5, the side members were bent during the collision. This means that the impacts reached side members along a bumper reinforcement, allowing satellite sensors to accurately detect the impact.

There was accuracy of delta-V in the O-3 sideswipe test, although the contact area is exterior to a side member on which a satellite sensor is fixed.

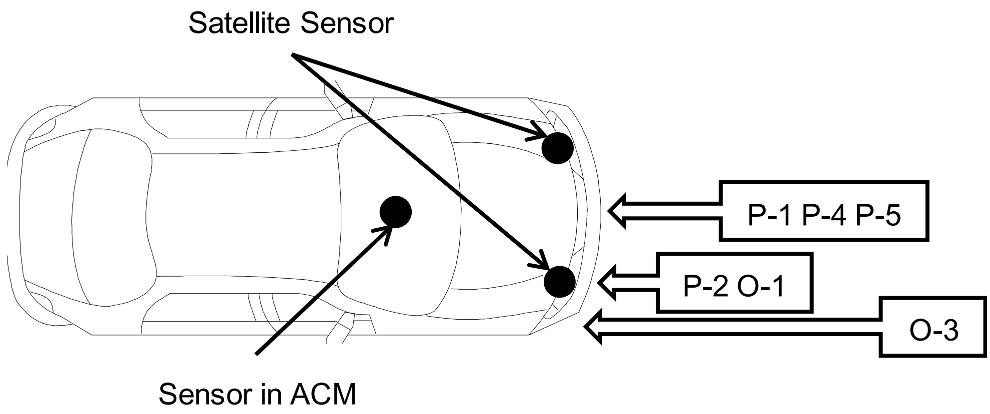

Figure 5 Position of accelerometers and impact points in each crash test

Comparison of the maximum delta-V and the delta-V versus time history data recorded in the EDRs with the results calculated from accelerometers indicates that maximum delta-V in a collision with large deformation at the vehicle centre (P-1 and O-1) results in a non-negligible error. This is attributable to large deformation of the ACM, which is positioned at the bottom of the centre console (Fig. 5). In P-1 in particular, the centre of vehicle was seriously damaged, breaking the bolts retaining the ACM and displacing it from its mounting. There is also significant error in P-5, despite the damage to P-5 being small and there being no damage to the ACM mounting. The cause of this error is unknown, so further research is needed.

The collision period typically ends at about 100 ms, so the time history of delta-V increases up until around 100 ms and is flat thereafter. Note that delta-V in test P-4 continued increasing slightly after 100 ms because the pole fell onto P-4's bonnet after the collision.

CONCLUSION

This study evaluated the characteristics of EDRs to better understand their performance and improve traffic accident investigations. Six actual car crash tests were performed and analysed, focusing on EDR crash data obtained in collisions with narrow objects. Pre-crash data from EDRs were very accurate and reliable. Satellite sensors detected impacts even when the impact point was far from the sensors, due to bumper reinforcements. Post-crash data from EDRs varied, and large errors in delta-V were seen in some tests. One reason for significant error was major damage to the ACM.

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Conversing with mobile phone while driving and its impact on driving behavior

M Papadakaki*, G Tzamalouka**, C Gnardellis***, T Kontogiannis ****,
D Sampson*****, E Anipsitaki*, E Vasilaki*, M Papanikolaou*, J Chliaoutakis*

** Laboratory of Health and Road Safety, Department of Social Work, School of Health and Social Welfare, Technological Educational Institute of Crete, TEI Crete, Estavromenos, GR 710 04 Heraklion, Crete, Greece*
*** Department of Health Care and Social Unit Administration, Faculty of Management and Economics, Technological Educational Institute of Athens, TEI Athens, Agiou Spyridonos Str., GR 122 10 Athens, Greece*
**** Technological Educational Institute of Messolonghi, Nea Ktiria, GR 302 00 Messolonghi, Greece*
***** Department of Production Engineering and Management, Technical University of Crete, Plateia Agiou Titou, GR 731 32 Chania, Crete, Greece*
****** Virage Simulation Hellas Ltd.*

Abstract – The current paper reports on the results of a pilot study aiming to investigate the effect of mobile telephone use on the driving performance of 5 amateur and 5 professional drivers. Their driving acuity was tested through a driving simulator. Analysis and interpretation of the results occurred comparing the drivers' driving performance while talking, reading messages and writing a message on the mobile phone (intervention time) with the drivers' driving performance engaged in no activity (control time). The variables affected by the mobile phone were the "steering", the "lane offset" and the "duration of lane offset". Moreover, the drivers involved in a car crash in the last five years appeared to differ from those who were not involved in a crash in both "lane offset" and "following distance". The results of this pilot study will inform the design of a large experimental study on 50 professional and 50 amateur drivers.

1. INTRODUCTION

Road Traffic Crashes (RTCs) constitute the 3rd most frequent cause of death and injury on an international scale. Every year 1.2 million RTCs occur in European countries, while 50.000 people die in fatal RTCs, 1.7 million are injured and around 150.000 are handicapped. The productive years lost because of RTCs are more than those lost due to cancer and cardiovascular diseases [1]. Greece, occupies the 3rd place in fatal RTCs among the European Union countries [2]. In addition, RTCs are the 1st cause of death among young individuals (15-25 years old) in Greece. The severity of the phenomenon is also very alarming. In 1991 Greece presented 11 deaths per 100 RTCs, whereas in West Germany this was 2.5 and in Italy 4.5 per 100 RTCs. Although a decrease of 24% in the rate of fatal RTC was observed from 1991 to 2003, more recent data from the European Union rank 7 out of 13 regions of Greece among the 10 most dangerous regions in Europe for RTCs [3].

In the last two decades there is a wealth of research on the effect of mobile telephone use on driving performance and crash risk [4]. This scientific interest in mobile telephone has been led by the increased number of drivers (60% to 70%) using a mobile phone while driving and by the fact that 1% to 4% of the drivers use a mobile phone at any given moment during the day [5]. Epidemiological studies suggest that over 50 minutes a month of mobile telephone use during driving is associated with *a five-fold increase in accident liability* [6], with a *risk comparable to intoxication* at the legal maximum [7] and with a *higher proportion of rear-end collisions* [8]. A major issue of concern is that drivers do not consider mobile telephone use as risky as other activities a driver may be engaged with simultaneously to driving (e.g. food or liquid consumption, children's care while driving etc.) [9].

Research has identified a number of behaviours and measures that are affected by the use of a mobile telephone while driving. These include impaired gap judgment [10,11], reduced sensitivity to road conditions [12]; poor lane maintenance [13,14], increased heart rate and subjective workload [15,12], and a reduction in headway [16]. The most reported problem with using mobile telephones, however, is the increase in reaction times to driving-related events (e.g. brake lights, etc.), and an increase in the number of such events missed altogether [16-22]. This has a great direct influence upon driver safety. Research with simulators has confirmed that increased risk of mobile phone usage is highly linked to the impairment caused to some very crucial aspects of driving performance [13,15,19,24-25]. Dragutinovic and Twisk [5] acknowledged inattention and physical and cognitive distraction as the major effects of mobile conversation. Physical distraction occurs when drivers undertake multiple tasks while driving such as searching or dialling numbers in their mobile phone, while cognitive distraction occurs when drivers have to divert part of their attention from driving to a telephone conversation. Garcia-Larrea et al. [26] identified a general decrease in attention to sensory inputs, common to both handheld and hands-free telephones. This reflects a general consensus in the literature that though hand-held telephones maybe particularly detrimental to concurrent motor tasks, hands-free telephones can also interfere with driving behaviour [16,20,22]. Although evidence is strong, no consensus has been reached yet on the processes and mechanisms which explain this link between driving performance and mobile telephone use. Taken together the evidence thus far, suggests that conversing via mobile telephones (either hand-held or hands-free) interferes with the processing of visual information during driving. This may seem to contradict many studies that support sensory-specific attentional resources [27], especially the superior performance of both a visual and auditory task compared to two tasks that share the same modality [28-29]. However, multiple resource theory [30], proposes four dimensions on which tasks may overlap, and therefore, draw on the same limited pool of attentional resources. For instance, one dimension distinguishes between processing stages, including perception, cognition and responding. If the conversation requires cognition, or perhaps a verbal response to a question, this may interfere with any aspect of driving that employs those respective processing stages. Thus, multiple resource theory can happily accommodate the notion that a conversation could draw upon the same attentional resources that are used for critical sub-tasks in driving.

In Greece, there is no surveillance system or any registered data on mobile phone related crashes (Greek Ministry of Internal Affairs, 2007, 2008), although prevention of RTCs is one of the first priorities for the Greek government (Greek Ministry of Transport, http://www.yme.gr/?getwhat=7&tid= 21&aid=1750&id**)**. Despite the huge number of fatalities under driver causation, this particular area of safety research is still neglected in Greece. Additionally, in Greece there are no records on the number of drivers who use a mobile phone or the number of offenses or traffic collisions due to cell phone use while driving (Home Office, 2007, 2008). In contrast to other European countries, Greece has no academic Department or Division on Traffic Psychology in Schools of Behavioural Sciences or any institution of tertiary education. The Laboratory of Health and Road Safety (LaHeRS) is one of the few known centres that exist in Greece conducting research in the area of driving performance and road safety (www.ctr-crete.gr/lahers/). Previous observational studies conducted by LaHeRS have identified that Greek drivers lead certain lifestyle patterns – mobile phone use included – that increase the risk of a crash. This finding has been replicated in various studies (Medline indexed) and has introduced certain concerns about culturally-specific characteristics that may interfere with increased crash risk. As LaHeRS has been devoted to exploring the involvement of human factor in car crashes, it is among its objectives to use experimental research to gain a better understanding of the mechanisms and mediating factors in risk involvement.

In the light of these findings, the current research project aims to introduce a pilot study on the effects of mobile telephone use on driving performance through experimental and observational research methods. Among the main objectives of this pilot study were the following: i) preparation of the experimental facilities, ii) pilot testing of the research tools, and iii) familiarization of the research staff with the study procedures. This pilot study will inform the design of a larger experimental study on 50 professional and 50 amateur drivers, which has been scheduled to be carried out in order to produce up-to-date knowledge on the involvement of human factor in the phenomenon of road traffic crashes.

2. METHODOLOGY

2.1 Study participants/recruitment

A sample of 10 male drivers participated in the study (5 professionals and 5 amateur). The professional drivers were drawn conveniently from the professional drivers' registries and the main taxi ranks, while the amateur drivers were approached at public places by the researchers. The power of the pilot study was calculated "a-posteriori" due to the fact that the available data were randomly generated without any preliminary report produced by the project team. The inclusion criteria were the following: a) age above 18 years, b) possession of a driving license, c) sufficient reading, writing, and communicating skills, d) informed consent prior to participation in the pilot study.

2.2 Data collection

2.2.1 Experimental study

Procedures: Laboratory tests were conducted using the VS500M driving simulator manufactured by Virage Simulation Inc. TheVS500M driving simulator is comprised of the car cockpit mounted on a moving base that simulates the movements of the car while driving. The visual system consists of three High Definition 52" screens and two 19" High Definition screens which create a 210o visual field around the driver. The driver has at his disposal the exact same instrumentation and controls that he would have in a conventional car while, at the same time, the simulator records the performance of the driver for the later evaluation of his driving performance.

All the participants were asked to drive the simulator for twenty minutes. In the first ten minutes the drivers had to drive without using a mobile phone while the next ten minutes involved driving with the use of a mobile phone. The simulated environment involved the participant's car moving in the right lane, a second vehicle moving in front of the participant's car in the same lane, a third vehicle following the participant's car in the same lane and a fourth vehicle moving next to the participant's car in the left lane.

Each participant was instructed to drive while keeping the safety distance of 3 to 4 seconds from the front vehicle that was indicated by the researchers. In the event of participants' driving at a lower speed than expected, the front vehicle exited the highway and the experiment was cancelled.

The researchers spent 5 minutes to familiarize each participant with the simulator and the study procedures before the start-up of the experiment. Immediately after the short presentation, the driver had to turn on the engine of the simulator and start driving. During implementation, one of the researchers was in charge of monitoring the process of the experiment, keeping the time limits of each intervention task as well as maintaining notes in relation to the participants' performance. The second researcher was in charge of delivering the individual intervention tasks, such as calling the participants on their mobile and filling in the respective questionnaire. Participants' driving performance was recorded by a professional camera for reasons of accuracy.

Content of the intervention: The intervention contained different tasks/assignments. Participants' driving performance was evaluated while undertaking three different tasks using their mobile phones, which were assigned at the course of their ten minutes intervention time. More specifically, during the first minute (0'-1'), the participants drove without using their mobile phone , just to reach the ideal distance from the vehicle in front of them. Between the second and the fourth minute of driving (2'-4'), the participants received a phone call and had a conversation with one of the researchers (Task 1). Between the fourth and the seventh minute (4'-7'), the participants received two text messages and were instructed to read them out loud while driving (Task 2). In case the participants read the text messages before the end of the seventh minute, they were asked to repeat reading both texts from scratch. Between the eighth and the tenth minute (8'-10') they were asked to reply with a text message to the information that was requested from them through one of the received text messages (Task 3).

2.2.2 The self-reported questionnaire

A structured questionnaire was used to collect necessary data from the sample of the drivers that participated in the pilot study. Prior to their participation in the experiment, all participants were given an information note which contained all the necessary information relevant to the study such as the aim and the objectives of the research. Participants' right to anonymity and confidentiality were safeguarded and a written consent document was distributed and signed by them prior to the completion of each questionnaire.

A self-reported questionnaire was used to collect information from the participants who were involved in the experimental study. The questionnaire was designed to identify factors that predicted drivers' performance while driving. The self-reported questionnaire is divided into three sections. The first section elicited information on the age, the educational level, the marital status, the weight and height of the participants. The second section examined the driving patterns history of crash involvement and driving behaviours of the participants (total kilometres driven, involvement in driving violations, driving safety measures, engagement in any activities while driving etc.). The third section contained items related to the frequency of use, the beliefs about using a mobile phone as well as the precaution measures taken by the driver while driving, and simultaneously using the mobile phone. The questionnaire was self-administered and the interviewer's role was limited in providing clarifications when necessary.

2.3 Outcome Measures

2.3.1 Experimental study

The following parameters of the participants' driving performance were evaluated in both scenarios (with/without mobile phone):

a) <u>Following distance:</u> The following distance from the front vehicle was estimated in seconds (every value over 1000 was ignored).

b) Lane offset: Lane offset represented the distance in absolute value (in meters) between the centre of the vehicle and the centre of the lane.

c) Duration of lane offset: The duration of the deviation from the centre of the lane was also estimated when “lane offset” was greater than 0.3m.

d) Steering: The “steering” represented the deviation from the centre. “Steering” was evaluated with the values of -1.0 (100% left), 0.0 (absolute centre) and 1.0 (100% right). The value close to 0.001 was considered invalid, and thus ignored.

2.4 Statistical analysis

The statistical package SPSS v. 20.0 was used for the data analysis. A database, specially designed for the study, was developed for entering and storing the data. This database was evaluated for accuracy and completeness. The analysis included the following:

2.4.1 Within group comparisons

(a) Within each driver’s category (professional/amateur), comparisons were drawn between driving performance (the 4 parameters described above) while using a mobile phone and without using a mobile phone.
(b) Within each driver’s category (professional/amateur), multivariate models were developed to explore the effect of mobile phone use (3 scenarios of mobile phone used) as well as other variables of the driver’s background (socio-demographic information, driving patterns and history, frequency of use and beliefs about mobile phone) to measure driving performance (good/bad performance while using the mobile phone).

2.4.2 Between group comparisons

Comparisons (of the four parameters described above) were drawn between amateur and professional drivers in relation to their driving performance while using a mobile phone.

3. RESULTS

3.1. Socio-demographic characteristics

The socio-demographic characteristics of the participants are presented in Table 1.

Table 1. Socio-demographic characteristics of the participants

	Professional Drivers N=5		Amateur Drivers N=5	
	n	%	n	%
Age*	34.2, 4.764		35.40, 16.742	
Educational level				
a. Formal education	1	20	0	0
b. High school	2	40	0	0
c. Vocational training	2	40	2	40
d. University/ College	0	0	1	20
e. Postgraduate	0	0	2	40
Driving time per day				
a. 30m-1h	0	0	2	40
b. 1h - 2h	0	0	2	40
c. >3h	5	100	1	20

**Mean, standard deviation*

3.2 Within group comparisons

a) The non-parametric tests (related samples Wilcoxon Signed Rank Test) showed that “lane offset” within the “control” time differed at a statistically significant level from “lane offset” while reading a message (Task 2) and while writing a message (Task 3) (<0.05). Moreover, “steering” within “control” time was found to differ at a statistically significant level from “steering” at intervention time, and specifically from “steering” while talking on the mobile phone (Task 1) ($p=0.07$), “steering” while reading a message (Task 2) ($p=0.09$) and ”steering” while writing a message (Task 3) ($p= 0.05$). Likewise, “duration of lane offset” during the “control” time, was found to differ at a statistically significant level from the “duration of lane offset” while talking on the mobile phone (Task 1) ($p=0.028$) and while reading a message (Task 2) ($p=0.05$).

b) Non-parametric Mann Whitney tests were calculated to explore the effect of mobile phone use and other driver’s background information on driving performance. Based on the analysis, the participants who had an accident in the last 5 years differed in “lane offset” while talking on the mobile phone (Task 1) with the ones that did not have an accident in the last 5 years ($p<0.05$). Additionally, the participants who had an accident in the last 5 years differed in “following distance” while reading a message on the mobile phone (Task 2) with the ones that did not have an accident in the last 5 years ($p<0.05$).

3.3 Between group comparisons

Between group comparisons were run using non-parametric Mann-Whitney tests. Based on the analysis, no statistically significant difference was identified between the two categories of drivers in any of the outcome measures.

4. DISCUSSION

The aim of the current project was to produce up-to-date knowledge in the wider field of road safety research through observation and experimental research methods. Therefore, the main focus was on exploring how the human factors affect the driving performance while conversing on the mobile phone.

Through the pilot study it was found that the driving performance within drivers' categories (professionals and amateurs) was significantly affected by the use of the mobile phone. More specifically, the variables that appeared to be affected by the mobile phone were the "steering", the "lane offset" and the "duration of lane offset" which seemed to be worst when driving while using the mobile phone as compared to driving while not using the mobile phone. Moreover, within the group comparisons, the drivers who were involved in a car crash in the last five years appeared to differ from those who did not involve in a crash in both measures of "lane offset" and "following distance". This observation could be an indicator that the use of a mobile phone while driving may render drivers more prone to road traffic crashes. However, this conclusion could come out in a more concrete way through a large-scale survey.

The current pilot study was also important in identifying technical limitations that should be improved during the upcoming large-scale experimental survey on a larger sample of drivers. Among the issues that were identified as problematic, and were thus corrected, was the fact that the "control" time and the three different tasks did not have the same duration. Therefore, to compare the results that were produced from the different tasks with "control" time, it was necessary to have this number over time, in order to get a rate ("steering" variations per second). The same approach was also followed for "lane offset" measurement.

4.1 Conclusion

To conclude, the project has a high scientific value and a great social impact. It will summarize evidence-based knowledge produced with observational and experimental research in a country with limited epidemiological and research data on crash risk and driving performance. Additionally, it uses novel methods and cutting edge equipment to collect experimental data (visual models, driving simulations etc.). Greek bibliography does not contain any similar examples of experimental work in the field of mobile phone use while driving. Even at European and international level the collection of experimental data on the subject of mobile phone use while driving using simulators is an emerging technique, which however shows great promise. Finally, the project is expected to advance knowledge and introduce tools to be used in future interventions for primary and secondary prevention of road accidents and road safety promotion in various population groups.

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Field of vision of modern cars – a study to improve the evaluation of car geometries based on real world accident scenarios documented in the ADAC Accident Research

M Pschenitza*, T Unger*

*ADAC Technical Centre, 86899 Landsberg am Lech, Germany

Abstract - Today's volumes of traffic require more and more responsibility from each individual road user in their interactions. Those who drive motor vehicles have the singular obligation to minimise the risk of accidents and hence the severity of injuries, particularly with a view to the most vulnerable road users such as motor bikes, bikes and pedestrians. Since responsible and pro-active driving depends first and foremost on the visual information relayed by our eyes and the visual channel this requires good command of the traffic and all-round visibility from our driver's seat. Granted that human error can never be fully excluded, improving visibility around the car is nevertheless an urgent priority. To do so, we need to rate visibility in the most realistic driving situations.

Since the existing visibility metrics and methodology are not applicable to real-life driving situations, this study aimed at developing a new visibility rating methodology based on real-life accident scenarios. On the basis of the cases documented by the accident research project, this study analysed criteria indicative of diminishing visibility on the one hand and revealing some peculiarities in connection with the visibility issue on the other.

Based on the above, the project set out to develop a rating methodology allowing to assess all-round visibility in various road situations taking into account both driver and road geometries. In this context, the assessment of visibility while turning a corner, crossing an intersection and joining traffic on a major road (priority through route) is of major importance.

The first tests have shown that critical situations can be avoided by adapting the relevant geometries and technical solutions and that significant improvements of road safety can be derived therefrom.

INTRODUCTION

Mobility is a basic requirement in today's world. It makes people more flexible and autonomous. In an increasingly complex traffic environment, road safety and driver comfort are two aspects of locomotion which must be safeguarded and maintained. Increasing fleets and mileages require the active road users to be more responsible in their use of motor vehicles on public roads. To ensure sufficient levels of safety and comfort, state-of-the-art vehicles must be equipped with advanced active and passive safety systems and they must provide good all-round visibility as a matter of greatest priority. While vehicle development has progressed in terms of new safety technologies over the last few decades, visibility has increasingly taken the back seat in favour of vehicle stability and occupant protection. This has significantly increased the risk of seeing other road users too late, if at all, due to body design, small side and rear windows etc. joining to encumber the motorists' field of view. As a countermeasure, the useful visual areas in vehicles need to increase again. This can be achieved by means of cabin design or visual aids such as rear-view mirrors, cameras or sensors. If cars come equipped ex works with systems such as the above, these visibility-enhancing measures must become part of the respective assessment methods. Therefore, adequate tests must be developed which allow the assessment of the actual visibility features on the basis of criteria derived from realistic driving situations. Such tests would allow general guidelines for vehicle design to be derived. Adequate vehicle design levels of quality necessarily require the continuous development of new or adapted assessment methods to reflect the evolution of the latest automotive concepts. The ultimate goal of car manufacturers should be to support motorists in their responsibilities in ever more complex traffic environments and so ensure higher levels of road safety.

HISTORY

Looking at the history of automotive development, we will find that the risk for humans and the environment is no longer caused by technical failure in the vehicles themselves. Automotive technical development has shifted the balance of risk clearly towards human error. This is due to the fact that individuals today seem unable to cope with the traffic situation around them and the control of their vehicles because they are simply overwhelmed by the volume of traffic and the complexity of state-of-the-art technology. Assuming that trends in road and traffic development will remain more or less the same, the further optimisation of traffic seems to be harder to achieve than vehicle-related solutions. The main reason for this state of affairs is the complex political environment created in the federal German system. Implementing adequate changes in road and traffic infrastructures, such as restructuring the road network, is much more problematic than promoting targeted measures in automotive design and engineering.

The benefit of passive safety features and legal requirements such as seatbelts and buckling up, mandatory side impact protection or the development of airbags is evident in the massive reduction of road fatalities. Nevertheless the most promising approach in achieving more road safety lies in active safety solutions. The accident risk diagram in Figure 1 serves as an illustration of the potential of active safety features in reducing the severity of injuries.

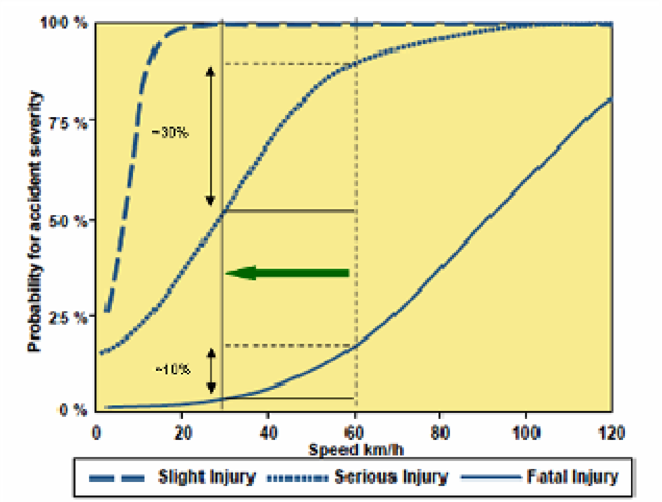

Figure 1: Impact of vehicle safety on accident severity [1]

Safety systems such as adaptive cruise control or brake assist reduce impact speed which is evident in the horizontal shift of the various curves in the diagram above. Where active systems reduce collision speed by 50%, e.g. from 60 to 30kph, this results in a much reduced injury risk (less severe injuries). The potential for reduction is around 30% for serious and severe injuries and approx. 10% for fatal injuries. Reductions in the severity of accidents of this order can no longer be achieved on the basis of passive safety measures since this technology has exhausted its potential and no major developments can be expected [1].

Active safety is not just a matter of improvements in the vehicles themselves, but also involves the driver and the man-machine interface. Interfacing here primarily means the flow of information the driver requires to control the vehicle. Responsible driving very much depends on the driver's fitness and information processing capabilities. Considering the factors above, incident-free driving at its best levels depends on the driver's experience, aversion or fondness of risk, motivation as well as the driver's physical and psychological fitness or condition [2-5]. Considering the fact that the driver acquires 90% of the relevant information through the eyes and related sensory system [6] it is quite clear how important the driver's visual perceptions are. However, in terms of safety, there is a deplorable trend in automotive design towards narrower fields of vision. For instance, some cabin pillars in state-of-the-art cars are likely to occlude other vehicles altogether so the driver perceives them too late, if at all (see Figure 2).

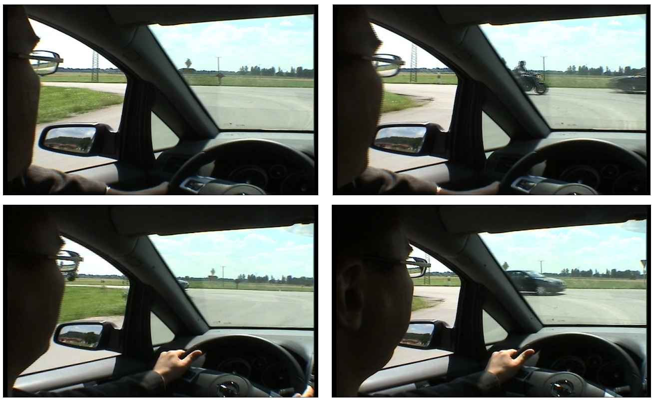

Figure 2: Other vehicles completely occluded by A pillar

The growing need for mobility in our society and the resulting higher traffic volumes require the driver to acquire and process more information quicker. This results in steadily higher requirements in terms of visibility from within contemporary cars and in visibility becoming a key element in active safety. From the driver's perspective, visibility is determined by a variety of factors which we may group in three categories [2]:

- ***External factors (environment)***
  The weather, position of the sun, surrounding geography
- ***Vehicle-related factors:***
  Vehicle geometry, interior layout, seat/mirror adjustment options
- ***Individual factors:***
  Height, physical proportions and posture of driver, seat position

In addition to the legal requirements for fields of vision, which are defined in purely geometrical terms, the automotive developer or designer needs to consider the driver's objective (angle values, occluded areas) and subjective perceptions and impressions (feeling cramped and unsafe) [3].
Since the requirements under which vehicles are developed and designed are so variegated, the developer/designer often faces conflicting goals with respect to the overall criteria. As far as all-round visibility is concerned, we have seen that this criterion is subject to some tensions between often contradictory aspects. Visibility from within a car is primarily influenced by body and interior cabin design, which is subject to certain contradictions. For instance, more massive or sweeping A, B or C pillars increase occupant safety in a crash. But on the other hand they reduce visibility to the outside. Some aesthetic aspects are dear both to the designers and the car buyer, for instance because they enhance elegance or sports car allure. At the same time, some design elements convey the feeling of more safety, e.g. high shoulder lines. But the narrower window surfaces become the more this affects visibility. In terms of aerodynamics, flatter windscreen angles and higher tail lines are usually inevitable but on the other hand they massively interfere with visibility. With a view to all-round visibility, there are tensions to reconcile also in terms of interior design. The position and layout of manual controls such as pedals, the steering wheel, the adjustment range of seats and other cabin elements have a direct impact on the driver's posture. In combination with individual driver anatomies, cabin layout and interior proportions are of primary importance for the driver's area of visual perception and perceptive capacity. It is evident that a constructive and design approach to all-round visibility is required since the direct fields of view cover only part of a vehicle's more or less immediate surroundings [2, 3].

STATUS

Legal aspects

The existing regulations with respect to visibility from within motor vehicles define the minimum requirements with respect to visibility. The requirements are attempting to take into account ergonomics as a primary factor to make the settings for driver/environment interaction as user-friendly as possible. This is the reason why the requirements are framed in very general terms, leaving much latitude in terms of personal responsibility and freedom of implementation to the car manufacturers. The problem here is that the variance in driver physical typologies is such that a one-for-all standard can hardly be defined on this basis. Obviously, the existing requirements are no more than a set of regulations intended to reflect certain ergonomic principles. As a result, they incorporate potentially contradictory requirements and moreover there is always the risk that the specific legislation may thwart the ergonomic intent altogether [2, 7].

Generally speaking, the legal requirements with regard to the design and layout of car windows and windscreens do not constitute minimum all-round visibility standards per se. The driver's forward (front, left and right) and rearward fields of vision (the latter defined only in terms of indirect visual aids such as rear-view mirrors or cameras) are defined separately. There is no unified definition for and treatment of all-round view. Moreover recent cabin body styles and designs are contributing towards a marked degradation of forward visibility. This is particularly obvious in the approaches to crossings and intersections where vehicles are occluded altogether by massive A pillars making them invisible to the driver (as shown in Figure 2). The case of rear view, for instance when joining a through route from a parallel slip road, is similar. In cases such as the merging slip road layout described above, the existing regulations and requirements are insufficient since they refer only to indirect visual aids. Here, driver assistance systems alleviate the situation somewhat but there is no legal framework for the use of such systems yet. The respective assistance systems are not mandatory, hence they do not need to be installed ex works. Another aspect with reference to the technical enhancement of visibility is that the relevant assistance systems are expensive and not readily affordable for all motorists. And finally, the increasing number of in-vehicle driver assistance systems may result in a sensory overload on the driver. This overload may be too much for some drivers and result in considerably slowing their responses. The drivers may not be able to control their vehicles optimally. With a view to car-to-car communication, the systems are not yet advanced enough to effectively compensate for the driver's difficulties in critical situations. We must ask ourselves how can it be possible that the car manufacturers have no problem complying with legal requirements whereas visibility from within cars constantly diminishes [2].

Physical and psychological limits

Processing visual information is one of the prerequisites for driving on public roads. Two factors are decisive for safe driving: one is sufficient visibility from within cars and the other is depth perception as a general ability. There are limitations which apply to both factors and can only partially be compensated. In terms of human anatomy, certain areas cannot be viewed directly or perceived only as a blur (monocular and binocular occluded areas). Such limitations can be overcome or compensated for by body movement and new angles of view. Visual aids such as mirrors and sensors have a positive effect on such limitations.

In terms of psychology, certain phenomena are not perceived correctly by the driver or perceived and evaluated correctly too late. Such errors are due to aspects of depth perception and absolute distance assessment, i.e. the realistic assessment of relative speed, acceleration and arrival time. The most common example here would be failure to recognise when an on-coming vehicle is on a collision course based on the minimal changes in constant bearing when vehicles approach an intersection at certain angles [8].

ANALYSIS

As a first step towards assessing vehicle geometries with a view to visibility problems we must refer to real-life accident statistics. In this case the relevant accident scenarios involve limited visibility accidents documented in the ADAC accident research database. For in-depth analysis, we looked only at collisions caused by passenger cars and where the cause of the accident was failing to see the other road user (see Figure 3).

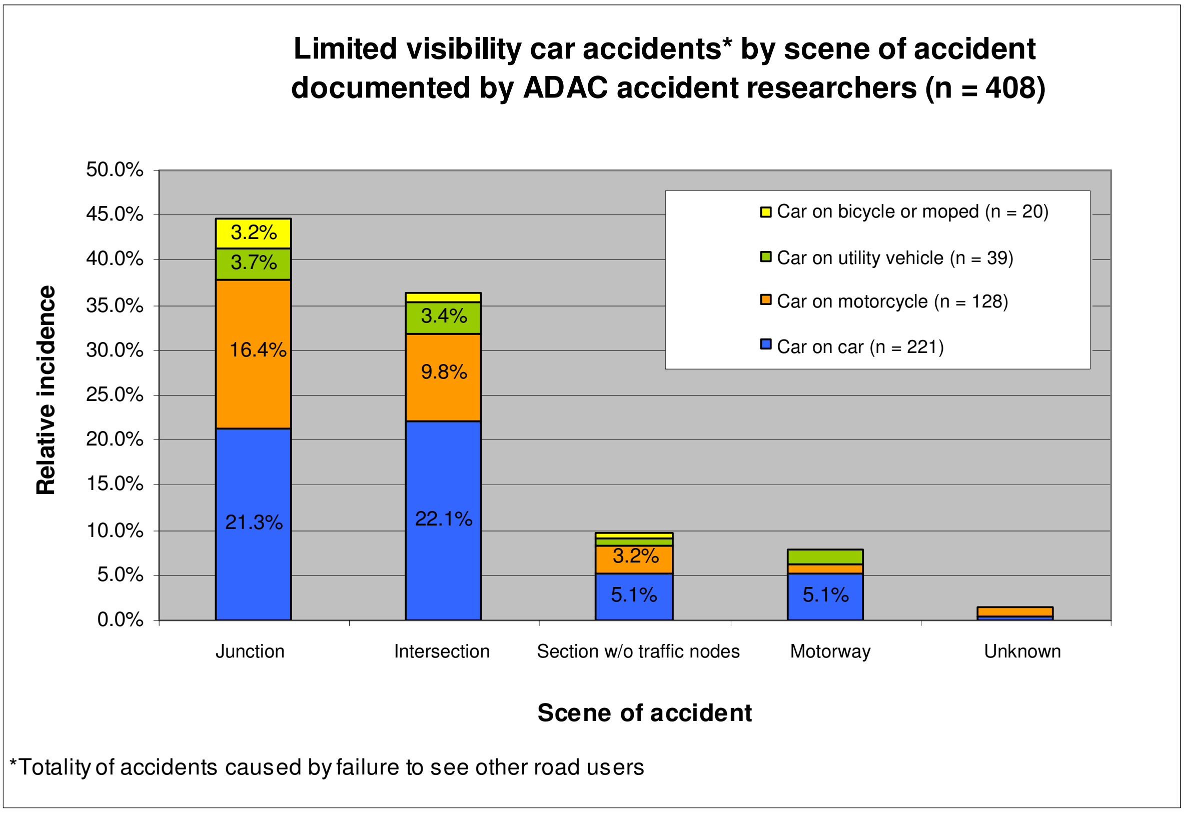

Figure 3: Limited visibility car accidents* by scene of accident

When it comes to limited visibility, crossings and junctions appear to be the most dangerous accident hotspots. The situation becomes critical because the vehicles approach from different points in a crossroads layout, further complicated by the disposition of the crossing or joining roadways and the relative angles at which they meet. This type of situation is more likely to give rise to the problem of limited visibility than for instance a same and/or opposite-direction traffic scenario. In order to make valid statements on the nature of the limited visibility (environmental, situational or vehicle-related), the actual crashes are analysed in more detail.
Assessing the relevance of window and windscreen layout in terms of safety requires a fundamental assessment of the traffic situation, accident constellation and last not least road geometry. The latter refers to the relative position of the colliding vehicles to one another. Road geometry is determined by the trajectory of the roadways (which may be straight, convex or concave) and the angle at which two roadways join. For the sake of clarity, the road geometries relevant for the types of accident under investigation were defined precisely (see Figure 4).

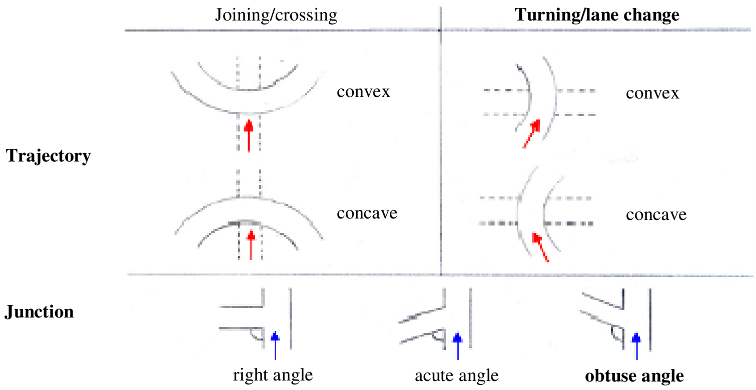

Figure 4: Definition of road geometries at the scene of the accident

Before drawing any conclusions on the impact of the individual windows/windscreen sections in terms of visibility, it appears necessary to discuss some conspicuous issues revealed by our analysis. We would like to point out that only limited visibility cases documented in the ADAC accident research database with a maximum of data such as operation logs, media coverage and last not least photographic documentation of the accident site were selected for a conclusive evaluation. Applying the above criteria, we obtained a total of 283 limited visibility accidents involving passenger cars which can fundamentally be classified into three types of accident. We investigated in detail two that are quite similar, i.e. joining/crossing and turning accidents, and in addition we also looked closely at accidents in same and opposite-direction traffic, i.e. lane-change accidents. Another important aspect in the accident profiles is the relative position to one another of the two parties in the collision. In accidents joining/crossing traffic there is a conflict between a joining/crossing vehicle obligated to give right of way and a vehicle having the right of way (at intersections, junctions, driveways or parking lot exits). In turning accidents, the conflict is between a vehicle attempting to turn off a road and road users approaching from the same or from the opposite direction. Table 1 shows the most frequent accident scenarios for the three types of accident investigated.

Joining/crossing accidents (n = 185)	
Turning left, opponent from left	44.3%
Crossing, opponent from right	25.4%
Crossing, opponent from left	17.3%
Turning left, opponent from right	10.3%
Turning accidents in cross-directional traffic (n = 72)	
Turn left, opposing traffic	87.5%
Turn left, same-direction traffic	9.7%
Lane-change accidents (n = 26)	
Veering left	80.8%
Veering right	19.2%

Table 1: Most frequent scenarios in the limited visibility accidents investigated

61% of the accidents joining/crossing traffic (of which approx. 44% left turns onto priority route accidents joining/crossing traffic and approx. 17% crossing) are collisions with road users approaching from the left. The reason for this causality is the relative closeness of the driver to the left-hand A and/or B pillar. When these objects are closer to eye level, they block out more of the visible area ahead than the more remote right-hand pillars. Nevertheless, in approx. 35% of all cases the right-hand (passenger) side of the car is in the focus in accidents joining/crossing traffic.

Both in turning/joining and in lane-change accidents, there is a clear prevalence in terms of the most frequent accident scenarios. In 87.5% of cases, the left-hand forward window/windscreen section is responsible for reducing the driver's command of on-coming traffic in left turns. The situation is similar in lane changes, where veering to the left (approx. 81%) is considerably more frequent than veering to the right (approx. 19%), were the side and rear window sections are responsible for any reductions in visibility. Also, our investigation revealed some peculiarities relative to road trajectories. More than twice as many accidents joining/crossing traffic happen on straight and convex crossing layouts than on concave setups. Straight roads (times four) and concave curve layouts (times three) are also more prevalent in turning manoeuvres compared with convex curves. Very often accidents caused by errors in lane changing happen on straight road sections (approx. 38%). But in lane-change accidents, the prevalence of convex curve layouts is even clearer (approx. 50%). This is due to the fact that there is more than a good chance for vehicles approaching from the rear to be in the driver's blind spot and therefore for drivers not to see them. It is also quite evident that most of the intersections/junctions where limited visibility car accidents happened were in themselves clearly laid out and offered very good visibility. In over 90% of all joining/crossing and turning accidents the view was completely free or at least this was the case for the immediate junction point (visibility ahead at least three vehicle lengths). Poor visibility of the other road users was therefore not attributable to structures or vegetation at the junctions etc. obstructing the view. This is very strong indication that the limitations of visibility are a vehicle-related matter.

Other investigations into limited visibility car accidents focusing on vehicle superstructures, year of make, colour of the vehicle(s) involved, the age of the driver and severity of injuries also yielded substantive new insights into visibility problems in state-of-the-art cars.

In terms of cabin/superstructure design a similar prevalence of certain car types involved in limited visibility car accidents is documented by ADAC accident research. In the totality of cars involved in limited visibility accidents, the number of hatchbacks and saloons as well as MPVs and SUVs with roomier and more elevated cabins (and usually better command of the road) are much more prevalent than estate and sports cars. Better visibility does not necessarily have anything to do with more spacious cabins or a more elevated driver's sitting position.

In terms of the year of make of the vehicle causing the accident, the vehicle-specific analyses show a clear shift in accident constellations starting with YOM 2005. The cut-off year of make roughly represents the period when cars with sturdier cabins and more massive cabin pillars were launched with the aim of boosting crash safety. We observe a strong reduction in the numbers of car-on-car crashes (approx. 15%) and car-on-utility vehicle crashes (approx. 4%). On the other hand, we witness an almost equivalent rise in the number of limited visibility car-on-bike accidents. Whereas the number of crashes involving bicycle and moped rose from approx. 3% to 10%, the number of car-on-motorcycle accidents rose by approx. 12%. Over the course of the last decade we have also observed an all-over growth of the PTW fleet, with only marginal increases from year to year (source: Federal Motor Transport Authority – KBA). Since the PTW fleet had a growth rate comparable with that of other types of vehicles, this cannot explain the rise in the number of car-on-PTW accidents. However looking at the statistical development of the PTW fleet and the launch of safer car cabins seems to account very well for the trend. Since PTW riders produce slighter vehicle silhouettes, they are simply harder to see approaching due to the bulkier safety-enhancing cabin pillars than other types of vehicles. To allow putting the figures obtained in the proper relation, the various types of accidents were evaluated by YOM of the causing vehicle. We observed that cars of more recent make caused an increasing number of joining/crossing and turning accidents whereas at the same time the number of car-on-PTW accidents in same and opposite-direction traffic decreased over the same period. This downward trend is also supported by our earlier finding that the risk of not seeing another road user at an intersection or junction is considerably higher than on stretches without crossroads or junctions.

Inquiries into the colour of vehicles shows that the colour of the opposing vehicle at least tendentially has an impact on the motorist causing the accident. Generally, the data from ADAC accident research reveals a trend with respect to the colour that coincides with a ranking of the most popular colours for newly registered vehicles over the last decade. Our data shows that the majority of the road users drivers tend to overlook are dark (grey or black) in appearance. This is not incontrovertibly linked with the vehicle-related visibility problems we are concerned with but we may conclude that the combination of dark paint and reduced visibility from inside a car has statistical potential and therefore represents an increased risk. We have also observed that bright paint schemes designed for "signal" effect (red but also blue), especially, are represented very often in limited visibility accidents. This also indicates that the cars causing accidents have vehicle-related visibility issues.

Another contributing factor is the age of the driver. Whereas in terms of driver age the official accident statistics are in accordance with ADAC accident research data, the numbers from limited visibility accidents relating to the age bracket of drivers age 25+ are clearly divergent. Comparatively, ADAC accident research shows a significantly lower number for the age bracket of 25 to 65 years of age (approx. 47%) than the Federal Statistical Office (approx. 59%) or the ADAC accident database (approx. 58%) for the totality of accidents on record for the same period. Setting off limited visibility accidents against the totality of accidents, the opposite is the case for the age bracket of 65+ years of age older people are twice as likely to have some sort of sight impairment that could make them unable to see other road users and cause accidents. Of course the capacity for concentration and sight decreases with age. On the other hand the elderly are less flexible and at difficulty compensating for any occlusions due to vehicle geometry. Unlike the previous analyses revealed, this type of visibility problem cannot be reduced automatically to vehicle-related poor visibility. However, the combination of advanced driver age and poor visibility represents a considerable risk. Another argument supporting the increasing vehicle-related visibility problems comes from a look at the "young driver" age bracket. Once again, the official statistics and ADAC accident research data are reconciled and there is no indication that in limited visibility accidents there is an age-dependent accident propensity due to lacking experience or inattention when driving. Again, we may assume that this type of accident is owing to vehicle-related visibility issues.

The last criterion for analysing limited visibility car accidents is the specific severity of injuries. The injury pattern illustrated in Figure 5 represents the severity of the injuries (slight to fatal) suffered by all persons involved in relation to the direction of the impact. It should be noted that this analysis includes all injuries suffered both by car occupants and PTW riders.

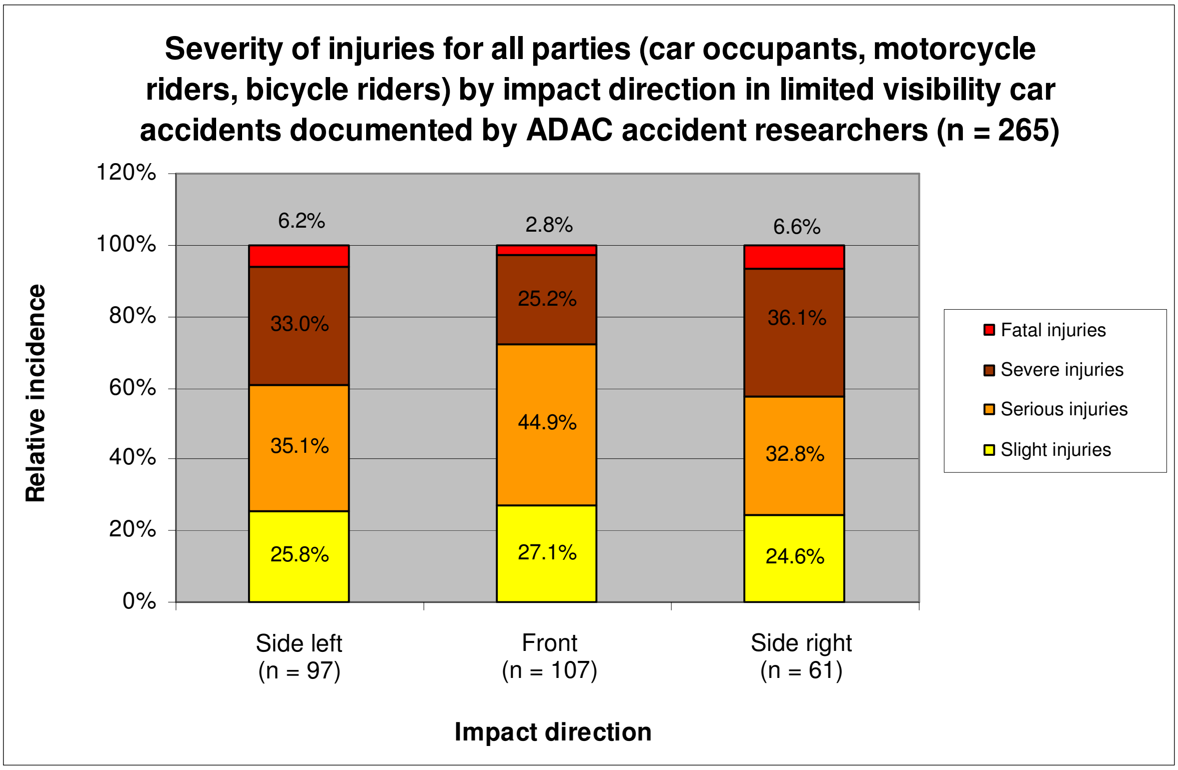

Figure 5: Severity of injuries in limited visibility car accidents by direction of impact

Slight injuries run to roughly the same percentage in all three scenarios. Since they range around a low 25% in all three cases, this emphasises the severity of injuries in limited visibility car accidents (in 75% of the cases injuries are serious, severe or fatal). However, the spread of injuries for side impact collisions relative to front impact collisions is noteworthy. Injury severity in side impact collisions is clearly greater: over 39% severe and fatal in left side collisions and almost 43% in right side collisions (brown and red). Severe and fatal injuries amounted to only 28% in frontal collisions. This disparity between the impact directions is the result of the vehicles' crush zone. In this respect, there is more potential in the front end structure of the vehicle than at the sides (doors and cabin frame). Deformations of the passenger cell happen earlier and are more pronounced, exposing the occupants to considerable injury risks.

We should also point out that, very often in the accident scenarios investigated (i.e. at crossings and junctions of all types), the road users involved were bicycle, moped and motorcycle riders or passengers. When collisions involve this type of road users the primary collision and subsequent fall result in severe to fatal injuries. This is also due to the fact that in this type of collision, the causing vehicles appear directly in front of the PTW riders and body contact between the riders and the vehicle body is immediate.

In analogy to the limited visibility car accidents we investigated other driving manoeuvres and situations for their potential for overlooking other road users. This includes cases in the ADAC database for which the cause of accident was defined as "errors in lane changing" or "ignoring up-coming traffic". However, based on the low amount of data available it was rather difficult to obtain clear results. The trends emerging from the analyses are similar to those in the limited visibility car accidents but they could not be used to draw representative conclusions. However, the lane-change accidents were used for in-depth evaluation of the accident situation (e.g. roadway trajectories, gradients and camber etc.) since they support important conclusions with reference to the assessment methodology we aim to develop.

METHODOLOGY AND TEST RESULTS

The results of the in-depth evaluation yielded the initial approach for the development of a methodology for the assessment of visibility from within cars. On this basis, with a view to devising a rating system for the scheduled tests, the windscreen/window sections in the test vehicles were included in weighting factors depending on their importance, that is to say depending on the degree to which the respective section of the bodywork contributed to a reduction in visibility in certain situations.

Furthermore an assessment of visibility from within a car requires a clearly defined test setup and procedure. An adequate test catalogue was developed to include certain traffic situations and all-round visibility tests. The selection of the specific manoeuvres was based on the preliminary analyses of accidents documented in the ADAC accident research database. The catalogue included 17 manoeuvres (joining/crossing, turning, merging into traffic and lane change) and 5 visibility assessments (manoeuvring into and out of parking bays and visibility of obstacles), which can be subdivided into three different categories. This includes an assessment of forward and rearward visibility (and the respective windscreen/window sections) and an assessment of general visibility. Depending on the situation, the side window sections may be crucial in terms of forward and rearward visibility when executing certain manoeuvres such as left turns or lane changes. It should be noted that the scenarios set up describe road sections, junctions and intersections with unobstructed visibility. The all-round visibility tests were also set up to reflect everyday practice and real-life road situations as closely as possible. To ensure that the test drivers executed the various scenarios precisely with a view to obtaining representative ratings, clearly worded test instructions needed to be compiled. The test instructions contain every procedural detail and specify the criteria to take into account in the various situations.

The test runs and the rating of the scenarios described in the test catalogue were executed by four test drivers. In their selection, we took care to make the test drivers representative in terms of height for the majority of real-life motorists. To obtain a well-weighted basis for assessing the impact of driver's height on the ratings we selected one test driver to be representative for the below-50th percentile (1.72m), two representative of the 50th to 95th percentile (1.82m and 1.85m) and one representative of the above-95th percentile (1.95m).

The scenarios in the test catalogue were run and rated independently by each driver in the respective test vehicle. The rating was based on the proven ADAC rating system. In this system 1 = very good and 5 = poor. The final overall rating also takes into account the aforementioned weighting factors and a number of additional upgrading or downgrading criteria. These factors and criteria aim to reflect the great variety of vehicle types and bodywork styles (coupes, convertibles etc.) as well as the manifold equipment options, e.g. driver assistance systems.

Results A pillar

The tests were conducted and validated with two test vehicles. The test results were compared with the results in the established ADAC all-round visibility test. The results for the smallest test driver correlate quite well with the metrics for the 50th percentile (1.75m tall) obtained in the ADAC test. The ratings for the taller percentiles are more divergent. This is obviously owed to the considerably higher seat posture of taller drivers. Figure 6 shows the comparative forward view on an unobstructed intersection with good visibility for the tallest and the smallest test drivers.

Test driver 1.72m   Test driver 1.95m

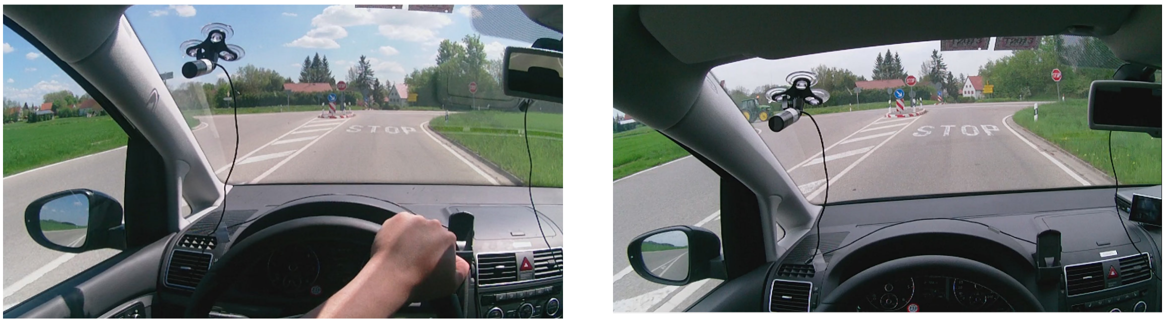

Figure 6: Impact of driver's height on forward visibility (compact MPV)

It is evident that view is more obstructed for the taller driver. Owing to the higher seat posture of the taller driver the angle of the driver's view changes to the extent that the A pillar occludes a wider portion of the driver's view than it does for a smaller person.

The run with the second test vehicle produces similarly divergent ratings. In both front end assessments, the worst ratings by far were applied in the ADAC all-round visibility test, whereas there is not much difference between the ratings of the individual test drivers. The extreme variation in ratings between the static ADAC all-round visibility test and the dynamic test run can be explained in terms of typical compensatory movements. Whereas the camera in the standard ADAC visibility test is fixed in one position, the real-life driver does not maintain a rigid posture, trying to compensate obstructions in visibility by adequate body movements. Slight movements of the head or torso are usually sufficient to compensate for the lack of visibility due to a higher seat posture. This can result in variations of up to 3 rating points. Figure 7 adequately illustrates this gain in visibility on the basis of the left A pillar assessment for the 1.72m test driver.

Figure 7: Impact of compensatory movements (supermini)

Results B pillar

As was the case with the assessment of forward visibility this test also shows a very good correlation of the ADAC all-round visibility test metrics with the results for the smallest test driver in the dynamic test. Overall, the worst ratings were also achieved in the standard ADAC test. Furthermore the ratings of the individual test drivers reveal a similar tendency for both sides. The most obvious observation is that the ratings of the taller test drivers are notably better than the 50th percentile rating. Here, the driver's seat posture is a decisive factor. Depending on the individual body metrics, each person has to adjust the driver's seat for comfortable posture. Smaller persons will slide the seat forward; taller persons will slide it back. The different seat positions result in different fields of view for the test drivers, e.g. when shoulder-checking. Figure 8 shows a shot taken at an acute angle junction.

Test driver 1.82m Test driver 1.95m

Figure 8: Impact of seat posture on visibility to the sides (compact MPV)

It is evident that for the smaller person, the B pillar is directly in the driver's field of view and blocks the view to traffic approaching from the left on the intersecting road. Taller persons sitting with the seat pushed back to the maximum have a different field of view. Sitting further back, the driver's field of view is actually wider to both sides of the B pillar and the driver's view of traffic approaching the junction is almost unobstructed.

Results C pillar and rear

The test runs did not reveal any problems observing traffic approaching from the rear. Road users approaching from the rear were always visible in the rear-view mirror and both test vehicles received very good ratings. However, the assessment of visibility to the rear depends on how much of the driver's view is obstructed by the C pillars. Strong variance was observed in the different test drivers' ratings. Again, the reason is grounded in the drivers' varying statures, the varying seat positions selected and the drivers' individual compensatory movements.

Test driver 1.72m Test driver 1.85m

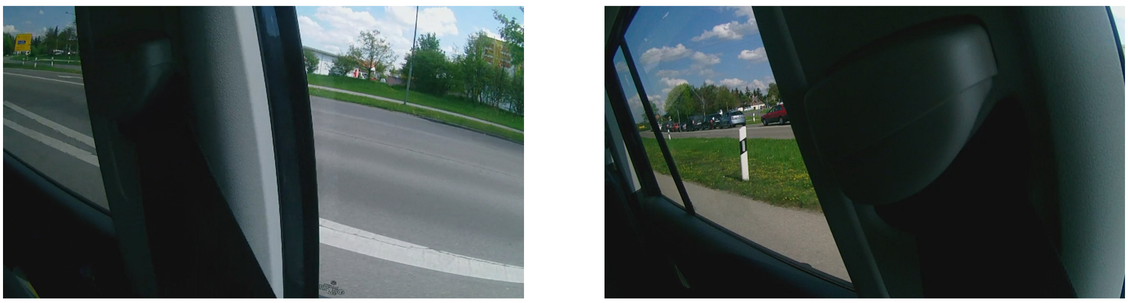

Figure 9: Impact of driver's height and seat posture on visibility to the rear (compact MPV)

Figure 9 is a graphic illustration of the above issues. Obstructions of view to the rear are particularly evident in merging manoeuvres. Effectively acquiring a view of any traffic approaching from the rear often requires extreme head and torso movements. Also, the position of the driver's seat and the driver's height have a fundamental impact on the ability to optimally observe traffic approaching from the rear or moving alongside the vehicle. For smaller persons sitting well forward, their rearward view is hardly obstructed by the C pillars. With hardly any interference from the C pillars, this window section received better rating from the smaller test drivers. Sitting further to the rear (rearmost seat position), taller persons are experiencing relevant obstruction from the C pillars. Since the rear section of most cabins comprises more bulky elements, notably the C pillars, the unobstructed field of view when drivers turn to check their rear is more reduced.

Overall results compared to ADAC all-round visibility test

For better comparability of the results, Figure 10 shows both the overall ratings given by the individual test drivers and the vehicle ratings from the ADAC all-round visibility tests (yellow mark). For easier orientation in terms of stature, the two relevant percentile points (50th and 95th) were marked with interrupted lines. It is evident from the diagram that despite the differences for certain statures discussed above, the overall results are similar.

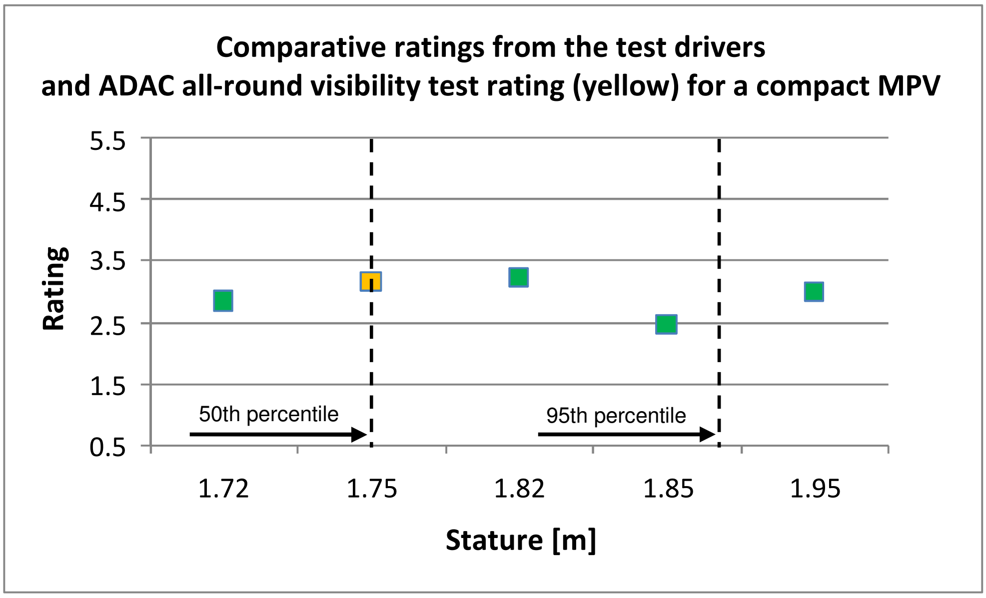

Figure 10: Comparative overall results (compact MPV)

This comparison shows more clearly that the static test setup in the ADAC all-round visibility test is compatible with the ratings in the newly developed test procedure. The variance in the ratings given by the test drivers on the basis of varying stature indicates that the static test setup and metrics ignore certain key factors of real-life human behaviour in road traffic. Since parameters such as stature, seat position and compensatory movements have decisive impact on visibility from within a car, such parameters must be included in the assessment of visibility.

Validation of methodology

Pertinent conclusions about the quality of the assessment methodology developed require a validation of the test procedure on the basis of the conspicuous issues noted during the test runs and in the analysis of the results. This investigation yielded a number of conditions that have to be met in putting this assessment methodology to work. One result of the validation is that certain K.O. criteria must be included in the assessment of visibility from within a car. It must be considered whether a vehicle being tested should be allowed to score a better overall rating if it scored a considerably lower rating in one of the test categories. Another decisive aspect is the robustness of the assessment/rating. The procedure allows only subjective assessments of visibility. The test does not ensure sufficiently high levels of reproducibility. The methodology is also heavily dependent on driver-related parameters such as stature and movement patterns while steering the car. Yet another factor is the overall traffic situation when running through the test catalogue. Since traffic at a given location and time may not always allow the inclusion of other road users in the visibility assessment, the ratings under different conditions may be subject to strong variance. Here, the selection of the test location is also decisive. Due to the high number and variance of test route trajectories and layouts, the test resists standardisation to a level that would allow precise and representative conclusions.

KEY FINDINGS

The analysis of the accident data from the ADAC accident research database and the consideration of the specifics of the particular area of operation of the ADAC HEMS crews clearly indicate that state-of-the-art cars have certain visibility issues in road traffic. Most of the relevant accidents occur at junctions and crossings presenting otherwise unencumbered visibility, i.e. there are no structures or vegetation obstructing the view. Limited visibility car accidents are caused mainly by motorists overlooking other road users approaching from the left while executing a merging/joining manoeuvre onto a through route, while crossing an intersection or ignoring opposite direction traffic while executing left turns. The overall percentage of 75% serious, severe and fatal injuries is indicative of particularly high injury risks in this type of accident. A group of road users particularly at risk are vulnerable road users, who are hard to see as well owing to their appearance or profile, such as motorcyclists and bicyclists. Car occupants are particularly at risk in side impact collisions as is the case in most limited visibility accidents.

PROSPECT AND LONG TERM GOALS

To allow effective measures for the improvement of car-related visibility, a dynamic visibility assessment methodology for cars was developed. Not only does it reveal the shortcomings of static assessment procedures, it also offers ways to compensate for such shortcomings by reflecting realistic traffic scenarios. It should be noted that the results obtained are based on some necessary assumptions and that the methodology needs to be verified with other test cars and adjusted where necessary. Furthermore, it must be ascertained how and to what extent the conclusions from this project can be incorporated in established and utilised test procedures. This requires adequate feasibility studies aimed at determining whether and how the new assessment methodology can be used to expand or to be combined with existing test procedures. Opportunities for development seem to exist with regard to extending the scope of percentile metrics to cover a greater variety of driver physiques and to improve correlation with test drivers of various statures. Furthermore, the inclusion of certain specific driving manoeuvres in static assessment methods seems promising with a view to optimising the assessment of visibility. This would entail chiefly the investigation of critical junctions, i.e. road layouts where roadway trajectories and the geometries of merging roads as well as the conditions of visibility are defined by certain characteristics. In addition to convex, concave trajectories, acute or obtuse merging angles, this would include gradients and the presence of structures and vegetation obstructing view. Effective solutions could also include reference to driver-related parameters such as stature and compensatory driver's movements.

It seems evident that there is considerable potential for improvement to achieve more road safety. This end requires both improvements in terms of infrastructure, legislative amendments and continuous progress in automotive engineering.

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E-Bicycles – Bicycles or Mopeds? Overview about the project "SEEKING – SAFE E-BIKING"

P Saleh*

*AIT Austrian Institute of Technology, Mobility Department, Vienna, AT

Abstract - SEEKING is looking for answers regarding electric powered bicycles and their relation to traffic safety issues. Does a cyclist need "E"? Is it as risky as riding a moped or are E-bikes creating conflicts with other cyclists? The project described herein, funded by the Austrian Ministry of Transport, has the aim of seeking answers to these hot topics. The SEEKING-team shows an in-depth investigation of vehicle dynamic sensing, together with subjective feedback of test riders to detect similarities and differences between conventional cycling and E-biking. Following an overview on the international status quo, measurement runs and their analyses are performed to find a set of preventative measures to make (E-)biking safer. A specific focus is the detection of curve handling, stopping and acceleration phases as well as conflict studies on course-based test rides and "real world" tests on cycling paths (naturalistic riding).

INTRODUCTION

This project was funded by the Austrian Road Safety Fund. It aimed at seeking answers to road safety related topics regarding e-bicycles and e-mopeds - especially for policy makers who develop roadmaps for the safe integration of electric powered bicycles and mopeds into regular road traffic. Finally, the results led to a catalogue of safety measures, e.g. legislative policies, infrastructural measures and technical rules (norms) for manufacturers to design reliable and safe electric two-wheelers.

Following a state-of-the-art analysis, the SEEKING-team (AIT Austrian Institute of Technology; BOKU Institute for Transport Studies at the University of Natural Resources and Life Sciences; KFV Austrian Road Safety Board; Government of Carinthia; Strombike.at) performed an in-depth investigation of vehicle dynamic sensing together with face-to-face interviews of test riders to detect similarities and differences between conventional cycling/moped riding and e-biking/-riding.

BACKGROUND

The riding characteristics of an electric two-wheeler differ from an ordinary bicycle, or a two-wheeler driven by a combustion engine (moped, scooter). The electrical support enables higher start-up acceleration and higher average velocities for e-bicycles. It is expected that these higher average velocities and changed acceleration behaviour result in increased conflict potential with other cyclists/road users.

Due to the lack of efficient passive protection, cyclists generally bear a raised injury risk in case of an accident. Compared to vehicle occupants, cyclists show a 4-times higher accident severity. Since this risk or rather the number of bicycle accidents is expected to increase with a rising number of e-cyclists, the main objectives of the SEEKING project are the expected changed driving characteristics and their influence on road safety. Within the scope of SEEKING, specific safety aspects for e-two-wheelers (e-bicycles and e-mopeds) are examined and relevant measures for increasing road safety are developed.

Riding dynamic effects and their consequences for e-cyclists and e-riders were scientifically compared to those of conventional bicycles and mopeds. Furthermore the conflict potential due to the interaction of e-cyclists with other road users was enquired and analysed. Following this analysis, preventive measures were derived for the safe use of electric two-wheelers.

DEFINITION

Since the development of single-lane two-wheelers with electric drive, many technical variants with different names were established on the market. Various names, as for ex-ample e-bicycle, e-bike, Pedelec, e-moped, e-Scooter, electrovelo can partially be as-signed to technologies, be rudimentarily defined in legal sources, or be considered as vehicle type designation of manufacturers or distributors. Electric two-wheelers are vehicles, which are pedal powered or non-pedal powered driven by an electric engine; the power supply is a (usually removable) battery pack. Depending on engine performance and design speed a classification according to Austrian law is as follows:

- "Bicycle" regarding the definition in the Austrian road traffic regulations (StVO, [1]) or as
- "Powered Two-Wheeler" (implies regulations regarding engine driven vehicles and driving licence) (EU directive in 2002/24/EG or §1 Abs 2a KFG [2]).

In this report the term electrical bicycle (abbreviated as e-bicycle) is used for single-lane bicycles with electrical pedal power. This corresponds also to the common term „pedelec“. The terms e-bicycle and pedelec are synonymously used in this case. Non-pedal powered two-wheelers with an electric engine are called electrical mopeds (abbreviated e-mopeds).

In summary this report defines and uses:

- Electrical bicycles (abbr. e-bicycle) for electrically supported bicycles, which are equipped with pedals, drive is dependent or independent from pedalling (in case that they do not exceed a maximum speed of 25 km/h).
- Pedelec (Pedal Electric Cycle) for the most frequent model of these e-bicycles, having the electrical support only if the pedals are moved; in Austria a pedelec is legally regarded as a „normal“ bicycle, if it is equipped with an electric drive with a highest permissible performance of max. 600 Watts and a design speed of max. 25 km/h [in accordance with. § 1 Abs 2a KFG].
- Electric moped (abbr. e-moped) for electrically operated two-wheelers, which have no device to use human driving power. The e-moped with a maximum design speed of 45 km/h and a maximum nominal continuous power of 4 kW is considered therefore as a powered two-wheeler and is referred to the subcategory "Motorcycle Bicycle" [in accordance with. § 2 Abs 1 Z 14 KFG].

In statements regarding all mentioned electrically supported or powered two-wheelers, the generic term e-two-wheeler is used.

METHODOLOGY

At the beginning of the project, the state-of-the-art regarding e-two-wheelers was investigated, including an enquiry on legal regulations. An analysis of national and international studies and the European (EU directive 2002/24/EG, [3]) as well as Austrian legislation (§1 Abs. 2a KFG) in the area of e-two-wheelers was carried out. The legal definition of e-bicycles and their difference to e-mopeds are particularly relevant. Information about known risks of the use of e-bicycles and e-mopeds and enquiries about critical facts/driving conditions when interacting with electric two-wheeler and other road-users were made.

Existing measures to increase road safety were identified and summarized from literature. Users of e-two-wheelers were briefly characterized, the trip purposes of e-bicycles and e-mopeds were indicated and motives for and/or barriers against the use of these vehicles were described. Conflict potentials as well as safety and accident risks, which result from using electric two-wheelers, were documented on the basis of existing studies. Aspects on driving dynamics and vehicle technology, road safety-relevant aspects of electric engines, sensor technology, battery technology, vehicle usage, handling, etc. were investigated and summarized in detail.

In order to examine the driving dynamics with e-bicycles and e-mopeds, test rides including different driving manoeuvres (acceleration, targeted braking, driving along curves etc.) with test persons were accomplished and data (speed, acceleration etc.) automatically stored. By means of face-to-face interviews, subjective experience and feedback of the test rides, attitudes to safety-relevant measures as well as personal behaviour and strategies for safe traffic participation with the electric two-wheeler were surveyed.

The synthesis from test rides, interviews and literature analysis finally resulted in a catalogue of safety measures as recommendations for increasing road safety of electric two-wheelers.

MAIN ACTIVITIES OF "SEEKING"

The three main topics of SEEKING are driving dynamics, conflicts and road safety measures.

Driving characteristics/dynamics

Driving characteristics/dynamics were measured and stored with GPS and three-axial accelerometers, using compact sensors (Smartphones) to ensure a quick and simple installation and not to affect the driving characteristics of the bicycle and/or the moped by the sensors including their power supply (weight, dimensions, etc.). In the first phase, analysis of driving dynamics and differences between e-two-wheelers and conventional two-wheelers took place on closed test courses under controlled conditions. Apart from the driving dynamic sensors, the provided bicycles and mopeds were also equipped with devices for data storage (by means of circular buffering). The evaluation of data clearly showed differences in the driving behaviour. Every test person drove the requested turns in a course (separate courses for bicycles and mopeds), with the target to drive each turn with similar time and speed. For both modes (electrical and conventional), 5 turns were driven (in sum 10 turns per participant). The adaptation effects while using e-two-wheelers were also examined.
The subjective feedback of the rides was also recorded in detailed interviews.

Conflicts with others road users (only with e-bicycles)

In the second phase of field tests („Real World Study "), e-cyclists were observed during "normal" traffic flow on cycle paths, and potential conflicts were recorded by video (Smartphones). Driving behaviour patterns or critical situations especially due to the interaction with other road users were examined; however, they were very rare thanks to the forward-looking driving manner of the test persons.
Similarly as during the course tests, subjective experiences were surveyed by means of face-to-face interviews.

Road safety measures

The main objective of the research project was, to work out road safety-relevant aspects due to the usage of e-two-wheelers systematically. This was accomplished by a synthesis of the evaluation results from literature, the examined test rides and the interviews. Possible risk potentials were identified and specific countermeasures were derived. The individual views of the test persons regarding different safety-relevant topics were gained in the interviews. Increased road safety, based on "pro-active" solutions and awareness raising measures, was the focus of the project SEEKING. The results were documented in a catalogue of measures.

SENSOR AND DATA ACQUISITION

For data acquisition a Smartphone (Samsung Galaxy S2) with light and compact sensors was used. GPS speed, three-axial acceleration and three-axial angular acceleration pitch, roll and yaw as well as a front video (fish-eye lens) were acquired and stored with the same device.
For sensor fixing special mounting plates were developed, which were equally applicable on every test vehicle. Therefore all e-bicycles and e-mopeds were equipped with the similar recording and sensor unit. Special attention was given to a stable fastening, without changing or damaging the vehicle frame.
A special software application (App) was developed, in order to capture and store data in parallel. The mobile measuring sensors were accessed by a basis station (laptop) via WLAN. With a specifically developed recording and controlling software, an operator could switch the app on/off, enter vehicle types, set time stamps manually or enter conflicts remotely, while the test person drives on the course. In between the test rides, data were transferred to a server automatically.

RIDING EXPERIMENTS AND INTERVIEWS

First the specific design of a course was drafted, in order to be able to record the different driving manoeuvres and features. In a further step the driving habits were tested and the design of the course was finalised. It showed a distorted form of an eight, with a straight entrance lane, different radii and curve lengths, two straight sections and one stopping field, where each test person had to stop at every turn.

The area for the course, which looked equally at each test, required a space of 17m x 25m. The design was prepared to allow typical inner-city manoeuvres and speedy accelerating on intermediary straights; however it was not possible to speed. Thus the driving conditions were partially demanding, while minimising high accident/injury risk for the test persons.
The e-bicycle test rides were carried out in Klosterneuburg/Lower Austria and in Vienna during the Vienna Bike Festival 2011 at the Rathausplatz. In total, data (measured vehicle dynamics and interviews) from 145 persons (141 interviews were recorded. They performed accident-free, but not always completely problem-free. Some additional measurements, as well as individual interviews (of experienced e-bicycle users, who did not want to do the test rides) were accomplished, in order to gather a larger amount of data and information. The course was driven with two different bicycle types (a city bike and a folding bicycle); in each case five turns with the conventional bicycle and five turns with the electrical drive (Pedelec; 250 Watts of rated power output). There were differences particularly in the engine control units and the pedal sensors, which were clearly reflected in the results of the observations.

The e-moped tests took place during a SAFEBIKE event (MA46) in the driving camp Pachfurth/Lower Austria. 60 test persons took part in the test rides and interviews. The course design was taken from the e-bicycle tests with a 1.5-times increase in size. The test vehicles (loans from the company FABER and Post AG) were of identical design, one equipped with a 50 ccm two-stroke combustion engine, the other one equipped with a 1400 Watt electric engine.

Some problems and differences during the test rides became evident (also later on during detailed video analysis). No participant crashed; nevertheless some critical moments were observed and recorded.

These moments consisted of 3 specific situations:

- Putting the foot on the ground to avoid a possible crash (foot off the pedal)
- Touching the borderline, sometimes knocking over of the cones
- Leaving the course (run-off)

57 conflicts were recorded during the bicycle tests. An accumulation of these incidents occurred during the use of electric power (39 conflicts with 18 riders) compared to rides without an additional drive (18 conflicts with 12 riders). There were no differences com-paring the bicycle types (Citybike

(28), folding bicycle (29)). As expected more difficulties were reported referring to the curves than to the straights.
In the conflict study (real world test) (with rainy weather and tricky manoeuvres) at a mixed walk- and cycle-track (Wörthersee in Carinthia) no single problem was observed. Only experienced e-cyclists were invited to these tests.

For the e-mopeds the incident "foot off the pedal" got replaced through "extreme inclination in the curve, so that the stand is touching the ground". The total number of conflicts was 22. No remarkable problems were encountered during the use of e-mopeds (11 conflicts with 8 riders using the electrical drive, 11 conflicts with 10 riders using the combustion engine). The e-bicycle and e-moped analyses are based on technical findings of the vehicle dynamics, which were measured in the trials and on the statements of the interviews.

Structure and content of the survey were primarily oriented towards the research questions and particularly towards road safety of e-cyclists and e-moped riders. The basic concepts of the questionnaires for both modes were similar, but particularly adapted to vehicle-specific characteristics and questions.

The focus of the qualitative interviews was on:

- Self-assessment of the test persons with regard to driving skills using the e-bicycle, experiences and behaviour in traffic situations;
- Transport policy attitudes regarding road safety issues of e-bicycle and/or e-moped, acceptance of measures;
- Reflection of the riders' experience in the test course.

After contacting the test persons, the process of the interviews was roughly divided into three parts:

(1) Questioning before the test ride,
(2) test ride with observation of the test persons by the interviewers,
(3) Reflective questioning after the test ride.

The measured test ride data and interviews with the test persons were analysed regarding road safety-relevant issues and possible risk potentials.

Analysis of vehicle dynamics and interviews
Evaluation of the test-ride data and the interview results give an explanation about vehicle handling and riding behaviour with e-bicycles (in a test situation) according to vehicle types and different sociodemographic characteristics, and about experiences, self-estimation and attitudes towards bicycle transport policy measures.

It must be emphasized that due to the relatively small sample size no representative results could be achieved, but trends and characteristics of e-mobility in general can be derived.

The data analysis (plausibility tests) and evaluation of riding characteristic data, as well as the interviews were accomplished after completing the course tests. The data collected during the test trials by different sensors were examined. Data of the three-axial acceleration sensors (longitudinal x, lateral y and vertical z-acceleration) and gyroscope (roll, pitch and yaw three-axial angular accelerations) were corrected by separately measured calibration data and the (measurement) noise was removed (by smoothing). Based on the received yaw angle acceleration the actual yaw angle (heading) was determined by integration and trend analyses by means of section-wise linear regression models. With the aid of this signal and the longitudinal acceleration, starting and stopping manoeuvres were recognized. In addition, 6 specific course sections with different yaw angle were detected, corresponding to the 3 straight lines and the 3 curves of the eight shaped track. The section recognition was realised by a hidden Markov model.

For further analyses the measured rides and/or individual turns of the trials were removed, in case they contained severe conflicts and were classified as distorting and not representative in a manual examination (including the videos).

The analysis of the interviews was carried out independently. The focus was on descriptive analysis, since the majority of the acquired data had nominal or ordinal character. The evaluation itself was oriented on the categories of the interviews and was analysed gender-specific.

It delivers information and answers to following contents and questions:

- Sociodemographic data of the test persons (gender, age, education, possession of a driving licence);
- Experiences with e-bicycle or e-moped, e.g. opportunity and frequency of use, experienced conflict situations in road traffic;
- Strategies of the active cyclists and e-cyclists to be safe in traffic (e.g. defensive driving habits, respect to pedestrians, giving priority to the road users, use of cycle paths);
- Objective and subjective safety (safety feeling when cycling, helmet use);
- Estimation of reasons for dangerous situations for e-cyclists and others;
- Acceptance of bicycle traffic measures (e.g. mandatory helmet use, speed limit, mandatory use of cycle paths, number plates for cyclists);
- Evaluation of the test rides - evaluation of the test persons by the interviewer and self-assessment of the test persons.

During the e-bicycle tests 141 persons were asked in four days and at two locations (Klosterneuburg and Vienna), 137 of them participated in the course tests. Although attention was paid to have a well-balanced ratio of men and women, all age groups and of persons with and without e-bicycle experience, this goal could not be realised. The majority of the asked and recruited ones were men (71%) and only approximately one quarter of the test persons had experience with e-bicycles. In the e-moped-tests in Pachfurth (NÖ) the sample was 60 test persons with 93% male participation.

Due to the small sample sizes and the unequal distribution of the interviewed persons, no representativity of the results (i.e. no complete coverage of the population) is claimed. The output of data analysis refers to the gathered sample. Nevertheless recognizable tendencies and interpretations with regard to recommendations are tolerable, in particular when the results appear plausible in comparison with literature research.

RESULTS OF THE DATA ANALYSIS

The measured vehicle dynamics data were evaluated exploratively. Due to only partial control over gathered data, it could only be specified partially, which methods and statistical procedures were suitable, in order to receive information and answers to the project questions. Thus the provided evaluations were constantly adapted and the data were continuously fitted, depending on the insights supplied by proceeding analyses. Due to the descriptive kind of the evaluations graphic methods gave a fast and exact idea of the data. The used analyses are described briefly.

The basic contents were boxplots, histograms and density estimations, or their combination (violin plot). They all reflect different aspects of underlying distributions and cover many of the substantial parameters (three-axial accelerations, riding times per turn, angle of inclination, etc.). Estimation of a probability density function was done to avoid the problems of a simple histogram.

First analyses especially dealt with the influence of the numerous factors, which arose during the measurements. This was realised through an explorative data analysis, which divided the measuring data into specific groups and compared the resulting data distributions. In order to exclude a strong adaptation effect, the total number of 428 single analyses was split and analysed separately by the respective measured test turn 1 and 2 and the turns 3, 4 and 5. The adaptation effect, in order to be familiar with a e-bicycle, was measurable, and even slight differences between the tests in Klosterneuburg (more place for free riding prior to the test rides) and Vienna (cramped area, no riding possible prior to the test rides) were observed.

It was shown that apart from the use of the electric engine, the gender of the test persons had an influence. Looking at the variance („width“) of the estimated density curves for longitudinal acceleration, it is decreasing between “without engine” to “with engine” for both genders, and between men and women both without and with engine support. A higher variance points to more extreme acceleration values. The differences, ranging from 0.2 to approximately 1 m/s^2 and appearing to be small, are to be considered as highly significant regarding their distribution. A Levene test examinating equality of variances confirms this ($p \ll 0.01$ in all cases).

RESULTS OF THE VEHICLE DYNAMICS ANALYSIS/TRIAL DATA

- Differences between the test days were detectable; a longer learning period and a good briefing of the technology were favourable.
- Differences between the turns 1, 2 and 3, 4, 5 existed, there were recognizable learning effects.
- Differences between bicycle types (size, operability) were measurable but negligible.
- Differences between genders were obviously larger than between without/with electrical engine support.
- For most combinations (type of bicycle, gender, age etc.) it can be stated: with electrical engine the ride got faster (i.e. shorter time per turn); the differences are not very distinctive.
- With increasing skill a (slightly) better usage of the electric drive was evident, i.e. shorter times per turn and higher speeds were obtained.
- Extremely slow turn times in the course occurred for test persons with little bi-cycle experience or for extremely careful persons.
- Pedalling sensors and engine control units were relevant: the echo-sensor (a ring equipped with magnets) knows only On/Off of the engine and gives 100% performance; the pedal torque sensor had a time lag - this led to retarded accelerating and requires braking in bends (a moped driving style).
- Differences in acceleration behaviour - problems concerning vehicle stability and during braking.
- In the „Real-World Study” the test persons were experienced e-cyclists there were no problems (more experience meant safe handling of electrical bicycles).

RESULTS OF INTERVIEW ANALYSIS

The majority of e-cyclists can be described as male, well-educated and middle aged (45 - 60 year old) - an insight from the interviews, which is well covered by literature. In spite of rising sale figures in Austria, experience with e-bicycles is relatively small. Among 141 test persons, 34 persons (18 men and 6 women) had active e-bicycle experience, completed by 22 experienced test persons from the real world study in Klagenfurt. Conflicts with other road users in traffic exist but were reported rarely: Asked about dangerous situations with other road users (passenger car, cyclists, pedestrians) only one man with e-bicycle experience (in the parcours tests) answered with „yes“ (without any further details); all others had no conflict or accident at all. However nearly two thirds of the interviewees already experienced conflicts or dangerous situations while („normal“) cycling, in which conflicts with car drivers were most frequent (55%) compared with 30% cyclists and 29% pedestrians. These experiences corresponded with those of the e-bike experiences interviewees in Klagenfurt. They indicated priority violations through car drivers and inattention of pedestrians as problems in traffic. 27% of them already had conflicts with car drivers, 14% with other cyclists and 9% with pedestrians. However they added that the conflict frequencies with the e-bicycle were not higher than with the conventional bicycle. Nevertheless it is expected that e-cyclists have more conflicts than conventional cyclists due to the higher speed level.

Women generally indicated to feel safer while riding a conventional bicycle than riding an e-bicycle. Moreover, they seemed to be more cautious about their personal safety than men: They more often use a bicycle helmet. If men rode an e-bicycle, the helmet usage rate also rose in comparison to the usual bicycle.

E-cyclists are aware of the dangers and risks in road traffic and adapt their driving behaviour accordingly. Following the interview data (at the course and also at the Real World Study) they show respect for pedestrians, ride defensively in general, with adapted speed and ready to brake. Due to the numerous gaps in the bicycle traffic network, not only the bicycle paths are used, but also the carriageway and sometimes even the sidewalk.

The majority of the test persons handled the test course safely, which was approved by the observations of the interviewers and by the self-assessment during the test trials. The few uncertainties arose more frequently with the e-bicycles (narrow curves, higher speeds as well as sudden acceleration with the e-bicycles) and particularly by women; the test rides with the usual bicycles rarely caused problems. -. Test persons felt very safe with the bicycle - men to almost 100%, women were more critical. Also the Real World Study in Klagenfurt delivered no single conflict and problem; the majority of the test persons could always control the speed well and safely accomplished even the up and down riding of the cyclist bridge.

Asking about infrastructural conditions and circumstances for the e-cyclists, the majority of the interviewees rejected the suggestion to be just allowed riding on the road instead of using bicycle paths. E-cyclists would like to have the possibility to use cycling paths - particularly women feel safer there - and would like to have a suitable infrastructure available. The quality of the bicycle lanes, specifically their width („too narrow“) was criticised by two thirds of the interviewees. It was interesting, however not surprising, that men rejected a speed limitation for e-cyclists, while more than half of the women agreed on that point.

The test persons were finally asked to give feedback on possible measures for a safe participation as e-cyclist in road traffic. The acceptance of a mandatory helmet use for e-cyclists was rather high (argued with higher average speeds with an e-bicycle compared to conventional bicycles). The opinions were matching with the personal data regarding the bicycle helmet usage, for which women again showed a higher acceptance. However a registration plate including insurance for e-bicycles was rejected by the majority. An obligatory bicycle examination (of traffic rules) was accepted among women, while obligatory bicycle training was rated rather unnecessary by men. However the latter is quite supported by experts, particularly for seniors and persons, who have not ridden a bicycle for long time.

FINDINGS OF “SEEKING”

The interpretation and knowledge from all evaluations (analyses of vehicle dynamics data, survey results and observations on site) prove, after reflecting the research questions and hypotheses, the following summary:

Differences of the riding dynamics between conventional bicycles and electric bicycles are definitely measurable and exist. While the recorded differences in the data with conventional mopeds and electric mopeds are neglectable small. Among the electric bicycles every vehicle model had own vehicle dynamic characteristics which are to be explained by different drive concepts and control units. Measured engine lag and inharmonious acceleration phases led to noticeable problems at the warm-up turns of the test rides. Clear differences, e.g. of the lap times, speeds, acceleration peaks etc. were identified driver-specific. The rider's behaviour had a stronger influence on the riding manner and therefore on road safety critical situations than the vehicle types itself. The evaluations of the interviews showed the good self-assessment of the test persons and an absolutely high road safety consciousness. The feedback of the riders' driving experiences and impressions were highly relevant for the analyses and interpretation of the measured data of the respective interviewee/test person.

The knowledge about riding experience and enrolment phase, especially at the track tests, was highly relevant. After two laps in the course almost all test riders were consistently and without any conflict on the move. During the familiarisation phase (bicycle and e-bicycle) the most problems were observed and documented with e-bicycles. At this point, it must be stressed that especially for beginners and returners' special training with an e-bicycle is highly recommended. In the test rides with (e-)mopeds no relevant conflicts were detected.

Based on the experiences from the course trials, the hypothesis whether experienced e-cyclists could handle e-bicycles safer was examined in the real world test in Klagenfurt on a challenging segment of a mixed pedestrian and cycling path. The hypothesis was confirmed to 100% – not a single conflict was registered. Only the rainy weather on the test day brought new knowledge relevant to road safety issues.

To every identified increase of the accident risk a suitable preventive measure, which was summarised into a catalogue of measures, was defined.

CATALOGUE OF MEASURES

To increase the safety of e-bicycles, the results of the literature research and the test runs were assembled and measures for road safety were derived. The measures can be structured into five categories:

- Legislative measures: Legal harmonisation of the Austrian regulations on the European level (especially concerning the definitions of e-bicycles and pedelecs), regulations regarding helmet use and offer of tests and training for e-cyclists.
- Infrastructural measures and traffic planning: A generous dimensioning of infra-structure according to the Austrian guidelines for bicycle traffic (cycle paths, intersections, curves etc.), integration of bicycle routes.
- E-Bicycle specific measures: Those measures include homogeneous standards of production to guarantee a high quality of e-bikes and to prohibit manipulation concerning the driving speed of e-two-wheelers.
- Awareness rising, education and publicity: Awareness rising should be intensified through competent sellers, flyers and brochures for free and trainings offered for (especially elderly) e-cyclists.
- Statistics and further research: There is still further research (e.g. infrastructural needs of e-cyclists, manipulation on e-bikes...) needed. For this reason it is important to have statistical data on the accident occurrences of e-bicycles.

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3 RL 2002/24/EG RICHTLINIE DES EUROPÄISCHEN PARLAMENTS UND DES RATES vom 18. März 2002 über die Typgenehmigung für zweirädrige oder dreirädrige Kraftfahrzeuge und zur Aufhebung der Richtlinie 92/61/EWG des Rates.

A better understanding of single cycle accidents of elderly cyclists

S. de Hair*, C. Engbers**, R. Dubbeldam**, Th.Zeegers***, H. Liers****

*TNO, Steenovenweg1, 5708 HN Helmond, The Netherlands,
**Roessingh Research & Development, Roessinghsbleekweg 33, 7522 AH Enschede, The Netherlands
*** Fietsersbond, Postbus 2828, 3500 GV Utrecht, The Netherlands
**** VUFO, Semperstraße 2a, 01069 Dresden, Germany

Abstract - Cycling supports the independence and health of the aging population. However, elderly cyclists have an increased injury risk. The majority of injured cyclists is victim of a single-sided accident, an accident in which there is no other party involved [1]. The aim of the project 'Safe and Aware on the bicycle' is to develop guidelines for an advisory system that is useful in preventing single-sided accidents . This system is able to support the elderly cyclist; enabling the cyclist to timely adapt his cycling behaviour and improve cycling safety and comfort. For the development of such advisory system the causes of singles accidents and the wishes of the elderly cyclist must be known. First step to obtain this insight was an literature survey and an GIDAS research. Unfortunately accidentology research with GIDAS did not give the full understanding of the pre-crash situations and (especially the behaviour related) factors leading to the accident. The second step was consultation of elderly cyclist through a questionnaire (n=800), in-depth interviews (n=12) and focus group sessions (n=15). This offered complementary information and a much better understanding of the behavioural aspects. Results concern the behaviour in traffic and identify specific physical (i.e. problems looking backwards over the shoulder) and mental issues. Furthermore, the needs and wishes for support in specific cycling situations were identified.
In conclusion; The GIDAS results together with the information obtained contacting the elderly cyclists enabled setting up requirements for an advisory system, which is useful in preventing single-sided accidents

INTRODUCTION

In the Netherlands, the number of fatal accidents in traffic has been showing a declining trend for years. However, the number of serious injuries has been increasing again since 2006. A large proportion of the number of people with serious injuries consists of cyclists. Approximately 80% of the seriously injured cyclists are victim of a single-sided accident, i.e. an accident in which no other party is involved [Weseman 2011].
Older people (65 years and older) are overrepresented in the group of seriously injured cyclists involved in single-sided accidents [Zeegers 2010]. On average the risk of older people to sustain an injury in a cycling accident is 3.2 times higher per cycling kilometre than for non-elderly [Zeegers 2010] and it is increasing with age. Within the group of older cyclists, people over 75 years are particularly vulnerable. The risk of hospitalization is more than 4 times as high for them [SWOV 2009]. Elderly cyclists tend to and need to adapt their behaviour according to their mental and physical abilities in order to avoid cycling accidents [Hagemeister 2011].
Beside the risk of cycling, cycling also offers positive aspects:

- It is good for the health
- It keeps people mobile and independent.

However, it is thought that cycling accidents may be further prevented and cycling comfort enhanced when more (specific) information about traffic conditions is known by the cyclist in advance. The general purpose of the project 'Safe and Aware on the Bicycle' therefore is to specify requirements (wishes, needs and expectations) in order to come up with recommendations for a feed-forward system that provides the elderly cyclist with information, which enhances safety and increased bicycle comfort. The proposed system might have the following functions;

- To inform in advance about a safe route for the elderly cyclists.
- To inform about dangerous conditions in advance and while cycling, e.g. the weather
- To warn about potential hazardous locations and/or situations while cycling
- To warn about potential dangerous behaviour while cycling.

METHODS

To improve the general understanding of the accident mechanisms and causes, accident analysis studies have been performed and reported in literature. So far, most studies on bicycle accident analysis are based on police records [SWOV 2009]. These studies, however, are not representative for the occurring number of accidents, nor for the number of cycling injuries: Bicycle accidents are highly under-reported by the police (current registration rate = 5 %). Hospital records might provide better insight in the number of accidents and injuries, but also hospitals do not register all accidents: Often treatment or hospitalization does not take place when minor accidents occur. Hence, the actual number of accidents is very likely to be higher compared to what is stated in police records and 'light' single-sided bicycle accidents resulting in minor injuries are underrepresented in official statistics [Zeegers 2010, SWOV 2009]. Many policymakers and regulators base their cycling policy and changes in cycling infrastructure on the official statistics. Therefore, causes of single-sided accidents with minor injuries, which do not end up in (hospital or police) statistics, are not recognized as problematic [Hagemeister 2011].

To obtain a better insight in single sided accidents of elderly cyclists (65+) the following information sources were used; Starting with a literature survey and a database research (using the database of the German In-Depth Accident Study GIDAS). The literature survey was used to get a good overview of the problems of single sided accidents, like critical situations, characteristics of elderly, risky behaviour and accident causation. GIDAS was used to give more in-depth knowledge on the accidents. On top of this desk study the elderly cyclists were consulted through a questionnaire (n=800), in-depth interviews (n=30) and focus group sessions (n=15). The questionnaire was used to obtain general information about the elderly cyclists, critical cycling situations and potential technological solutions and user needs and desires. The interview was used to complement the results gathered in the questionnaire and to obtain in-depth information about topics that were found significant in the questionnaires. The focus group sessions were used to obtain requirements for the specification of the advisory systems based on user needs.

Methods literature review

The aim of this review was to obtain insight in risky situations and activities elderly cyclist face during their cycle trip. Further was investigated which accidents and accident types take place and what happens during the last few minutes before the accident takes place (actions and behaviour of the elderly cyclist). All with the scope to obtain data which is needed to specify a successful advisory system, in order to prevent single sided cyclist accidents. The focus is on accident causes related to behavioural aspects and habits and the bicycle itself, also attention is paid to infrastructural causes. This study focuses specifically on risky situations in order to come up with recommendation to overcome this kind of situations. Parameters taken into account are: age, cycle use, age, registration level, accident types, trip characteristics, risky situations.

Methods accidentology research

In the literature review, often a reference to GIDAS is used. No specific query to single sided accidents is known. The GIDAS database has been used to obtain in-depth knowledge of single cycle accidents. The Netherlands does not have such an in-depth database. Therefore it was expected to be useful in addition to the Dutch national statistics: the police registration (BRON) and the hospital registrations (LIS). One has to take into account that German and Dutch circumstances can be different. The GIDAS database is mainly used for accidents with motorised vehicles, but offers also single sided cyclist accident cases. As a first step a statistical analysis to the in GIDAS registered single sided cyclist accidents with elderly (age 50+) was executed. As an indication; GIDAS consists of 5.590 injured cyclists after weighting with German national statistics. 31% of them are aged 50 or more. 17% of these accidents are single sided accidents. Parameters taken into account in the GIDAS analysis were: accident type, cyclist age, gender, location, injury type and level, time of day, weather and accident cause. As a second step the accident descriptions of the target group were obtained, in order to get a better understanding of the accident cause and circumstances of the pre-crash situation. In the GIDAS analysis all MAIS levels were taken into account.

Methods questionnaire

The participants included men and women of 65 years and older who were still cycling. Most participants in this study were participants who signed up for the cycling school from the Dutch cyclist union. The participants received the questionnaire from the instructor that day or, if preferred, they received a link to the internet version of the questionnaire. Other respondents were recruited by the union for elderly (KBO): The paper questionnaire was attached in their monthly magazine. All of the respondents who filled in the paper version returned the questionnaire with the attached self-addressed envelope.

First some demographic aspects were asked, such as gender, age, province and living environment. Furthermore, the elderly cyclist was able to describe their experience regarding bicycle usage, physical and cognitive impairments, (adaptation of) cycling behaviour, critical cycling situations, technological experience and wishes with respect to technological support. The questions on technological experience were added to gain insight in the use of technological devices by this group of elderly cyclists.

Methods interviews

At the end of the questionnaire, participants were asked if they were willing to participate in an interview. They could fill in their email address of telephone number if they were interested. All respondents were approached by telephone or email to make an appointment for the interview by telephone. An informed consent and an information letter were send to the participant by mail prior to the appointment. Themes in this interview were initially comparable to those in the questionnaire: demographics and bicycle details, frequency of cycling and most common destinations, physical and mental limitations, technology experience. Our first aim with the interviews was to check if similar answers were given compared to the questionnaires. In a second step, it was possible to ask more in-depth questions on specific items. Furthermore, the wishes and needs for support in specific cycling situations were identified. All interviews were audio-recorded and analysed afterwards by content analysis. Besides elderly cyclist also 'cycling school' teachers and bicycle traders were interviewed, in order to obtain an view of the elderly cyclists needs as objective as possible.

Methods focus group session

Focus group sessions were organised in order to obtain information on technological details and specification of an advisory system. Participants are recruited via a local new paper and a local foundation. Intakes were done via telephone. The meetings took place at Roessingh Research & Development and lasted for 2,5 hour. Feedback is obtained on the following topics: kind of warning, location of warning, warning frequency and duration, extra desired functionality. Per topic people were asked to come up with their preferences. After 2 workgroup sessions it was observed that people find it difficult to imagine the advisory system and its parameters, resulting is less useful results. Therefore it was decided not to conduct more focus group sessions.

RESULTS

Literature review

The causes of single-sided bicycle accidents can be related to infrastructure, the role of the bicycle and behaviour of the cyclist as has been indicated in accident analysis studies based on police and hospital records. Concerning the role of the infrastructure [Schepers 2008] and [Ormel 2009] show for example that 20% of the single-sided accidents involve a collision with an object, such as a pole or a curb. Slippery road and bumps in the road are also frequently given as an accident reason. Furthermore several studies show that junctions are often experienced as problematic [SWOV 2012]. In general, intersections are experienced as complex situations, where attention simultaneously has to be given to various traffic situations. Especially turning left is experienced as a problem by elderly people. Regarding the role of the bicycle in single-sided accidents, little is known. Elderly often make use of a relatively common bicycle although there are many alternative bicycles available with a low entry and

mirrors, especially designed for seniors. However, elderly often choose not to use such adapted bicycles because of multiple reasons [Berveling 2012]. Older people feel uncomfortable about these bicycles. Purchasing such a bicycle confronts them with their disability and these bicycles are not yet well established in society. Besides that, their disability normally occurs very gradually and older people generally like to hold on to old habits and behaviours. Furthermore, bicycle related causes almost never occur independently. Usually the condition of the bicycle plays a role in combination with the behaviour of the cyclist [Reurings 2012]. Although the study of [Kruijer 2013] has illustrated that the use of electric bicycles does not lead to more accidents, [Fietsberaad 2012] suggests that the use of electric bicycles can lead to accidents when the engine (pedal support) starts too abrupt.
The behaviour of cyclists is reported to play an important role in single-sided cycling accidents studies from hospital and police records: For all age groups, about half of these accidents were related to cycling behaviour such as a clumsy steering or braking manoeuvre or getting hitched during getting on or off the bicycle [Ormel 2009, Kruijer 2013]. According to [Ormel 2009] one fourth of the cyclists aged 55 and older indicated getting on or off their bicycle as the cause of the accident. This is significantly more than in other age groups (8%). Because the above cycling behaviour studies are based on data from respondents who have been treated at an emergency room, little is known about the 'light' cycling accidents and their mechanisms and causes.
So far, only one study analysed the relationship between cycling abilities or behaviour and accident mechanisms of self-reported cycling accidents [Hagemeister 2011] show that the proportion of single-sided cycling accidents increases (65% vs. 55%) and are more frequently related to own cycling behaviour (60% vs. 50%) compared to cycling accidents in hospital records. As a comment, we note that the victim's own role is usually overrated in self-report studies and therefore external roles are usually underrated. The risk of sustaining a cycling accident could be related to physical impairments such as problems getting on or off the bicycle or not-compensating for sensory difficulties. Most cyclists indicated to adapt their cycling behaviour according to their physical and mental impairments, e.g. older cyclists often get off their bicycle or turn left indirectly (first cross one street and then cross the other). Sometimes elderly have trouble to look over their shoulder: They trust on their hearing or they indicate their upcoming change of direction well in advance without actually looking over their shoulder. Interestingly, the study of Hagemeister and Tegen-Klebingat shows that adults aged 60 years and older violate traffic rules. The researchers connect this behaviour to the search for subjective certainty. Additional subjective findings show that elderly cyclists are scared when they are passed by traffic with a high difference in speed. In particular, a shock reaction occurs when elderly do not hear the vehicles and therefore do not anticipate the overtaking manoeuvre.

Accidentology research

The first step in the GIDAS analysis was a parameter analysis of all single sided cycle accidents. GIDAS consists of 22.347 reconstructed accidents. In 6.641 a cyclist is involved. 6.239 cyclists are injured. After weighting with German national statistics 5.590 injured cyclists remain. Of these cyclists 31% are aged 50 years or more. There is a higher proportion of female (54%) than male (46%) in this category. About 12% of the cyclist accidents are single cyclist accidents. A comparison between the target group (50+) and the reference group (age 15-49) showed that the target group has a higher share of single accidents (17% compared to 12%), a higher share of driving accidents (loss of control) and a lower percentage of turning off the road. Further is remarkable the high percentage of accidents with animals and physical disability of cyclist of the elderly cyclists. With increasing age the likelihood on a severe injury (high MAIS value) increases (figure 1) as well as the risk of a fatal accident.

Focussing on the single cyclist accident only the following can be concluded. The major proportion of the accidents take place in urban area, and on a straight road. Most accidents take place during day, with increasing age the share increases. As expected, hardly any accidents occur during rain or snowfall. The road conditions show an equal share of the age categories. About 80% take place on dry roads. Of course, these numbers cannot be used to draw conclusions on the risk levels involved.
Figure 2 shows the top 10 of the most common accident types of single cycle accidents in GIDAS. Besides the accident types, the accident causes were studied. With respect to accident causation the

following can be concluded. The analysis is based on the official German list of accident causes. The list of available accident causes is not very detailed and not always appropriate for the accidents studied (single sided cyclists accidents). The accident causation study shows a high proportion (50%) of ‘other mistake of driver’ (including ‘inattention’, ’distraction’, ‘missing controllability’). Alcohol as accident causation factors decreases with age. In general 20% were intoxicated. In comparison to the reference group the share of bad road condition as contributing factor increases with age. Inappropriate speed is not only a problem for younger cyclists. Often this parameter is mentioned in combination with special road conditions. The share of physical disabilities increases significantly with elderly cyclists. Obstacles on the road (including animals) is a problem, especially for age group 75+. Technical deficiencies (including bad lighting, brakes, tyres) are not essential. Transport of baggage as contributing factor is low (5%) although the share increases with cyclist age. The behaviour of the driver and road user are not coded as initiated factor, but often as contributing factor. 75% of the injured cyclists are male. However, there is an increasing share of women aged 75+ (probably due to their higher life expectancy). The share of recreational trips is large. The number of shop visit increases with age. The share of travel to work (above age of 65) is as expected not present anymore. The share of cardiovascular diseases increases. Probably the real values are higher, as people forget to report it. A strong correlation between medication and illness can be seen.

As alternative approach to the top 10 accident causation overview, the accident descriptions of all single cyclist accidents of elderly cyclists were investigated. Based on this a new classification was made, that fits better to single cycle accidents. The results are shown in figure 3. This offered insight in the scenarios, but unfortunately the focus was more on the crash part of the accident than the pre-crash part. For the advisory system specification the pre-crash part is most relevant.

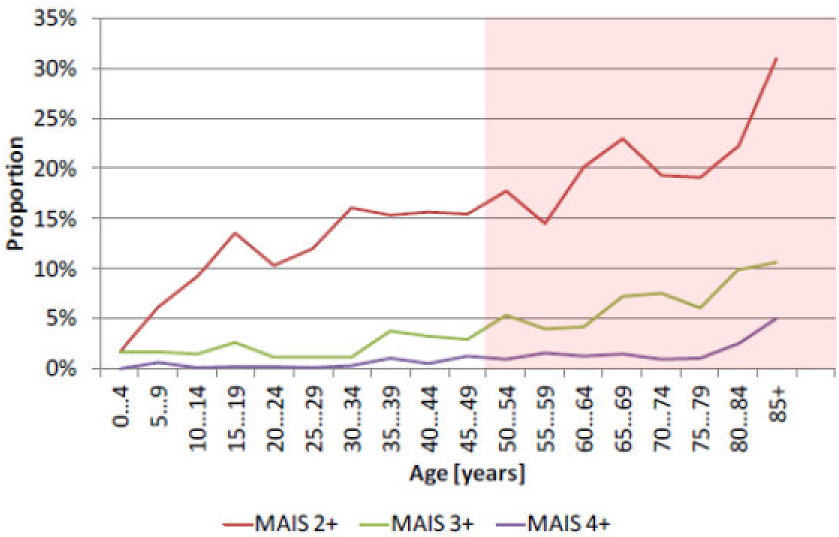

Figure 1: Injury Severity level (MAIS) of injured cyclist as a function of age [registered in GIDAS weighted with national statistics (n=5590)]

Loss of control accident on straight roads	141	25,0%
Other accidents	799	17,3%
Animals on the road	751 deer, 752 unsupervised pet, 753 supervised pet	9,5%
Sudden physical disability	762 dizzy spell, 763 other	7,9%
Other loss of control accidents	199	5,1%
Loss of control accident while turning off	121, 123	4,7%
Loss of control accident due to road condition	181, 182, 183	4,6%
Loss of control accident on a steep hill up/downwards	151, 152, 153	4,4%
Loss of control accident in a bend	101, 102	4,3%
Sudden vehicle damage	771 tire, 773 brake, 775 other	2,7%

Figure 2: Top 10 single accident types of age group 50+ [registered in GIDAS weighted with national statistics (n=5590)]

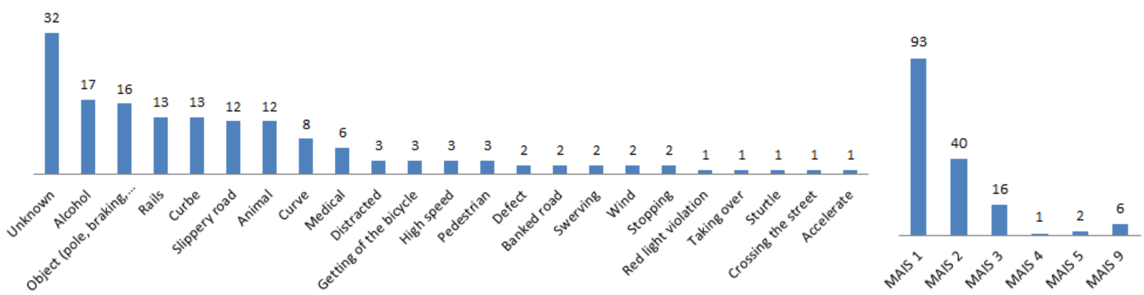

Figure 3: Classification of single sided cyclist accidents in GIDAS based on accident description [single case analysis]

Questionnaire

In total 1400 questionnaires were spread. In total 879 questionnaires were completed.
The mean age of the participants was 72,4 years (SD = 5.7 ; range = 65 - 104) with an even distribution between men and women (men: 45,9%; women, 53,9% men). Most respondents lived in a

village of rural environment (75%) compared to a city (25%) and were the provinces from Gelderland, Overijssel and Noord-Brabant.
Most participants used a ladies bicycle (70,8%) instead of a men's bicycle (28,5%). 41.1% used a normal bicycle, 29,9% used an electric bicycle and a normal bicycle and 29.1% used an electric bicycle only. The participants who had an electric and a normal bicycle mostly used the electric bicycle (62,4%). The electric motor was most commonly located in the front wheel (52.3%), in comparison with 30,1% in the rear wheel and 10,2% in the crankshaft. 21.4% had an adjustment to the bicycle, of which 5,1% used a mirror. 69,6% of the elderly participants stated not to have any adjustment. Most participants cycle more in summer than in the winter. In summer, more than 60% of the participants cycled every day in comparison to less than 40% in winter.
Most common cycling destinations were shopping, visiting friends and recreational tours. Of the participants, 64.8% replied not to consider the time of the day when cycling and 19.7% did not consider the weather condition when cycling. Participants that did consider the weather, mostly considered snow, slippery conditions and rain. In bad weather conditions the participants reported to adapt their behaviour: more concentrated (37,5%), more cautious braking (31.4%), slower cycling (25,1%). 88% stated that he or she is in good health and is moderately active on a regular basis (figure 4). The majority (85%) of the participants felt confident on their bicycle.

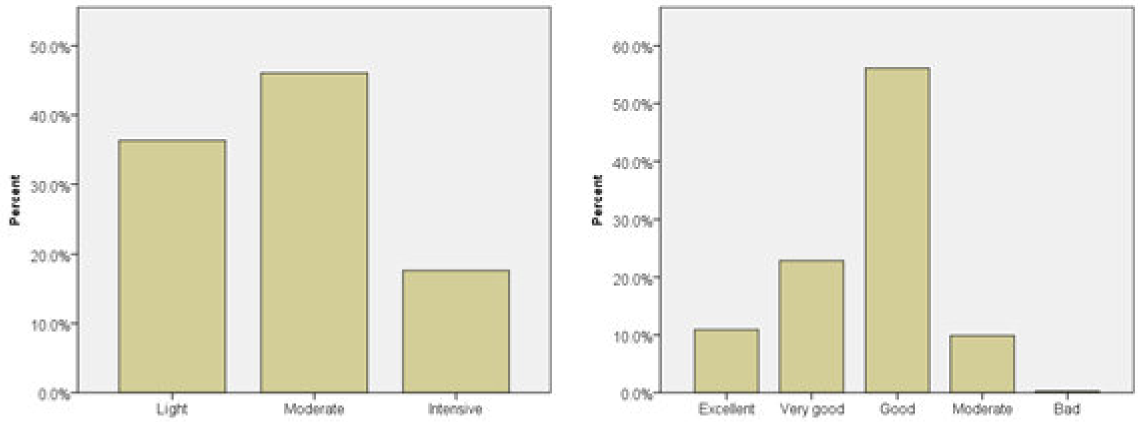

Figure 4: (left) activity level of participants (right) health level of the participants [based on questionnaire feedback]

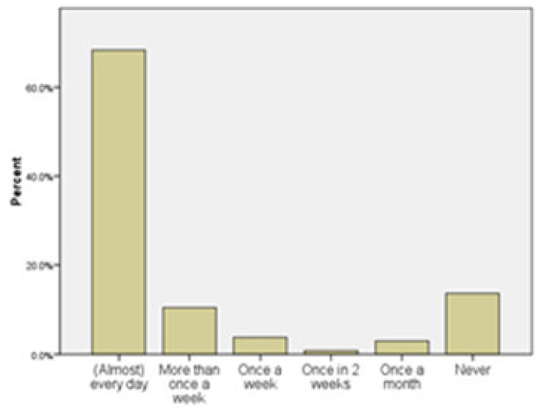

Figure 6. Use of computer/laptop

Figure 5: use of computer/laptop of the participants [based on questionnaire]

About 50% of the participants stated to have physical problems, such as; Sore knees (13,7%), limited endurance (12.4%), stiff and/or sore neck (11,1%), reduced hearing ability (11.1%). 35,9% of the participants mentioned to have mental problems i.e., reduced reaction time (12,4%), fear to fall off their bicycle (12,2%), feeling uncomfortable in messy, chaotic or unclear traffic situations (16.7%).
More than 80% adjusted their cycling behaviour since they became 50 years old; they became more

patience in traffic and paid special attention to reducing speed on time. Almost half of the participants (42,9%) admitted to violate traffic rules, for example; 32% cycled on the wrong side of the road and 22% cycled on a pedestrian area.

47,3% of the participants had fallen of their bicycle since they became 50 years old at least once. Many causes were mentioned, but most common causes were slippery roads, fall while getting on of or off their bicycle or a collision with the curb. Poles and other obstacles are frequently mentioned to be badly or not visible.
The use of electronic devices such as computers and laptops was quite high within our group of elderly cyclists (figure 5). Only 17% stated never to use a computer or laptop and internet (figure 5). The use of smartphones and tablets was less frequently reported; 23% uses a tablet and 17% a smartphone. Navigation systems are not frequently used by the participants in this study, 76.2% does not use a navigation system.
The needs and wishes for support in specific cycling situations were identified (figure 6). This table shows the importance of several functions for a feed-forward system. Of our elderly cyclists, 81.5% would like to be informed about dangerous locations; 82.1% would like to be warned about a slippery road, 76% would like to be informed when there is traffic behind them and 71.4% would like to be informed about an upcoming traffic situation.

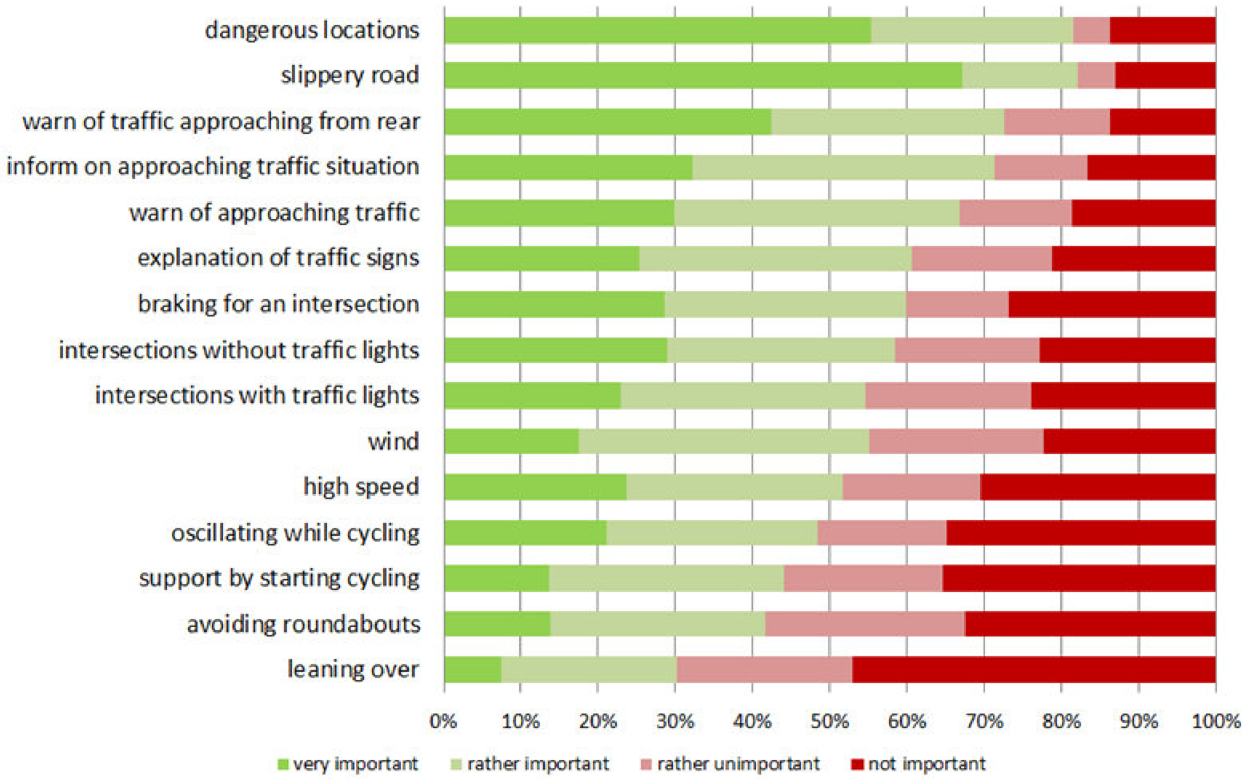

Figure 6: Overview of needs and wishes for support in specific conditions; importance of feed-forward functions [based on questionnaire]

Interviews

Results from the personal interviews complemented the above knowledge and provided more in-depth information.

Twelve interviews were conducted. The mean age of the participants was 81,7 years and consisted of 15 men and 13 women. Eight were living in a rural environment and four were living in a city. Five were cycling on a normal bicycle, three on an electric bicycle and 4 used an electric bicycle as well as

a normal bicycle. All respondents cycled in summer, two of them did not cycle in winter months and six cycled less. Only three also use their bicycle when there is snow or the road is slippery.
In general, the respondents with an electric bicycle were satisfied with their bicycle. However, some participants mentioned to have some trouble with the weight of their bicycle and the transition between a normal bicycle and an electric one. Some respondents complained about the advice they received from the bicycle dealer.

Seven respondents stated that they adjusted their cycling behaviour since they became 50 years. The most frequently mentioned adjustments were cycling with more patience, stopping more frequently and avoiding busy situations or times. Almost all (n=10) of the participants stated that their health is (very) good, meanwhile they all experience physical complaints e.g. suffer from a stiff and/or painful neck, less endurance or loss of strength. Many of the respondents mentioned that they have some difficulties with chaotic, busy and unclear traffic situations. Others also have trouble with a busy intersection. Actions that were named as more difficult are getting on and of their bicycle, looking backwards over their shoulder and taking a curve with high speed. Most of the respondents had troubles with racing cyclists and youth passing by at higher speeds. They do not hear the people who use a road bicycle and are frightened by them.
Most people had some trouble imaging a feed-forward system, but when given some examples they became enthusiastic. Nevertheless, some had some doubt about the technical possibilities and suggested the system should not be too complicated. Eight participants responded positive on using a feed-forward system, three had trouble imaging feed-forward system and one was negative. Regarding the mode of providing a warning or information, only one participant was positive about the signal being given by a display, the others preferred visual, audial or vibration signals.

DISCUSSION AND FUTURE WORK

This study aimed at obtaining wishes and needs of elderly cyclist regarding a feed-forward system. The results of the interview and GIDAS analysis gave a good starting point for the exploration of the problem of single cyclist accidents. Overall the GIDAS results are in line with other sources. Based on the accident descriptions obtained, GIDAS shows a large share of cases in which alcohol, and objects (poles, rails, curbs and pets) play an important role. In contradiction to the Dutch statistics GIDAS shows less cases in which stepping on/off the bicycle, slippery road, cyclist being startled, curve and road bank side play a prominent role in accident causation. The injury level and injured body regions are well described and are complementary to the Dutch statistics. The risks based on GIDAS analysis are mainly related to infrastructure, in line with the police registration. The GIDAS database is designed for investigating every type of traffic accidents. The most users use the database for analyses related to motorized vehicles. The database is hardly used for the investigation of single sided cyclist accidents, which makes some parameters used to characterize a cyclist accident less suitable. A good example of a less suitable parameter for cyclist accidents is the coding of the accident causation and cyclist's mistakes. The accident causation for single sided cyclist accidents is often unknown or "other mistake". In the accident description the pre-crash information is missing in most of the cases. Unfortunately this made the applicability for the definition of an advisory system less useful as expected before. Nevertheless GIDAS is complementary to the Dutch statistics with respect to injury description. For specific use cases this GIDAS knowledge can be used. The GIDAS research offered the following insights:

- Accident classification based on manoeuvres does not offer a good insight in risk factors, in contradiction to what it normally does offer for cars.
- For single sided cyclist accidents the combination of factors leading to the accident is more significant to discriminate what happened rather than the manoeuvre. This requires another type of accident classification for cyclist accidents than used for motorcycle accidents.

The results of the questionnaires and the interviews provided detailed information about elderly cycling behaviour in traffic and their wishes for support. Mental and physical problems and their effect on cycling behaviour were identified. Most common bicycle destinations in this study were shopping or leisure tours, which are, according to [Ormel 2009], the types of rides during which most single-

sided accidents happen. This indicates that the most common cycling destinations are also the most risky ones. Most common problems mentioned by the participants in this study corresponded to literature, such as intersections [SWOV 2012] and turning left [Hagemeister 2011]. Remarkable is that the elderly in this study admitted to frequently violate traffic rules, this has been shown previously by [Hagemeister 2011]. According to Hagemeister, violating traffic rules is a strategy to enlarge their subjective safety, especially in complex situations. Alternatively, one could speculate that the smaller tendency of elderly to be sensitive to social control, could provide an explanation as well.
The respondents in this study used a computer, laptop and tablet intensively, which might indicate that they are getting used to modern technology.
So far, the results indicated that the elderly population is a risk group for falling off or with a bicycle: 50% of the participants reported a fall with their bicycle, which is in line with the findings from the self-reported bicycle accident study by [Hagemeister 2011]. Regarding impairments, especially, the inability to look over the shoulder and impaired hearing can be dangerous with the increasing use of quiet motorized transport (electric cars and motorcycles). Using a feed-forward system may provide support in such situations, e.g. by warning for traffic coming from behind. The interviews confirmed most findings of the questionnaire and proved to be a valuable addition to the questionnaire. Besides the interviews with seniors, several cycling instructors and bicycle sellers were interviewed. Their opinions and views were very valuable and important and complemented the results. Additional analyses are planned. Some relations need to be explored, for example; the relationship between violating the rules and fall history, the relationship between technology experience and feed-forward wishes or the relationship between physical and mental limitations and feed-forward wishes. In addition, differences between men and women and differences between the group who completed the questionnaire on paper and the group who completed the questionnaire online needs to be explored. Additional information about the feed-forward system needs to be further explored.
The main problems as identified in the questionnaires and interviews were confirmed, as well as the potential solutions. Further was identified that a relation exists between the main problems people experience and the solutions they are looking for. This indicates people would like to be supported for their main problem. In the focus group session only one type of advisory system was selected for further specification, namely the rear ward looking assistant. Other assisting system were not taken into account. People indicated they prefer to use a rear ward assistant rather than a rear view mirror. People are prepared to pay for a solution, but they found it hard to quantify the exact amount of money they like to pay for it. The following additional information is obtained from the focus group session: people like to be warned more often and early preferably displayed on their steering wheel. No common view on the type of warning was retrieved. It seemed to be rather difficult to imagine how a type of warning would feel like and what would be most preferable. In simple experiments (done within the project but not further described in this paper) it was found that people need to experience a warning in order to be able to judge their preference. Therefore it was decided not to proceed with the focus group sessions (in which people could not experience the warnings). The focus group sessions did offer insight in people's preferences with respect to system configuration settings; like for example they like to be able to switch of the device (when cycling in a group) or they only want to obtain a warning when they are really being taken over.

CONCLUSION

The GIDAS results together with the information obtained contacting the elderly cyclists enabled setting up requirements for an advisory system which will help to reduce the number of killed and severely injured elderly in single cyclist accidents. The information retrieval methods used in this study each have their own advantage. They are complementary and offer together a good insight in the problems of single sided accidents.

- The literature study and accident analysis study are good measures to start the exploration of the problem of single cyclist accidents. They give an objective view on the accident problems. However under-registration and the lack of detailed of pre-crash information require the need for more information. The in 2013 finished in-depth study of the SWOV offers complementary information.

- Questionnaires, interviews and focus group session are a subjective, but useful complementary method to gain insight in the pre-crash phase as well as the user needs and desires. The results are in line with the literature review and the accidentology analysis, but offered the potential to gain more in-depth information. This is essential to come to the design for the specification of an advisory system.

So far, we concluded that the older people in this study were in good health and cycle frequently. Although they stated they were in good health, they do have physical and mental problems. Half of all respondents fell of their bicycle since their fifties, which confirms that this age group is a risk group when it comes to falling off or with a bicycle. The subjects stated that they feel confident and secure on a bicycle, but when situations become complex or chaotic, they lose control. The respondents mentioned several situations in which they would like to be informed or warned by a feed-forward system. This might indicate that there is a need for such a system. The results of this study will be used within the project 'safe and aware on the bicycle' for recommendations and specifications for various applications to be used in a feed-forward system.

ACKNOWLEDGEMENTS

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Title: Did a higher distribution of pedelecs results in more severe accidents in Germany?

Authors: Joerg Moennich, Thomas Lich, Andreas Georgi, Nora Reiter

Robert Bosch GmbH, Corporate Research and Advanced Engineering Vehicle Safety and Assistance Systems (CR/AEV1), P.O. Box 300240, 70442 Stuttgart

Motivation and approach

There is a new trend in Europe and especially in Germany by the increased use of electric bicycles recently. This new vehicle category (includes pedelec, speed-pedelec, E-bikes) enables driving with electrical engine support [1].

In particular, the class of electrical bicycle with electrical support up to 25kph and maximum power of 250W (pedelecs) have the highest market share of approximately 95% [2]. This is impressively illustrated for Germany by the determined sales volume of the last years. At leasts in Germany up to 400,000 units were sold in 2013.

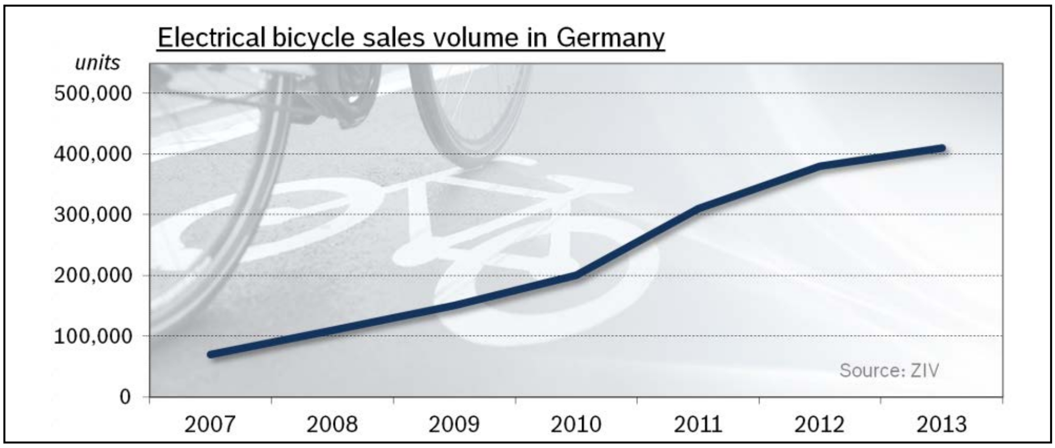


Fig. 1: Trend of electrical bicycle sales in Germany [2]

Considering a higher penetration and traffic participation in future as a consequence thereof the number of accidents involving these new vehicle types (especially pedelecs) will also be influenced. Hence the question arises how and in which way will be the impact towards the traffic safety in Germany in near future?

Did a higher distribution of pedelecs results in more severe accicents in Germany?

At this time it isn’t easy to awnser this question with available facts. Existing completed studies usually show only consequences of single events with involved e-bikes for example the result of collision between passenger car and pedelec with the maximum supported speed (25kph in case of a pedelec and 45kph in case of a speed-pedelec) [5]. A completed study which analyzed pedelec accidents of German in-Depth Accident Study (GIDAS) Database in detail gives first results regarding pedelecs in real accident situations. A small number of pedelec accidents (sample size of n=30) were available for the study and analysed. As result, no higher frequent occurrence of serious injuries in comparison with bicycle accidents was found [7].

Aim of the following described study, is to estimate with a pessimistic approach the impact of pedelecs (assumed higher speed than bicycles) towards the traffic accidents severity in Germany for

different penetration rates. A change in the traffic accident situation is not part of this study due to the fact that the influence of the rider behavior cannot be estimated at this point of time.
The common assumption is, that the usage of pedelecs and the driving behavior of their riders are different to conventional bicycles. This still has to be verified by more scientific investigations which should also include the behavior of other road users in interaction with pedelecs [8].

Till end of year 2013 no official accident statistics regarding electrical supported bicycles are available. For 2014 the new vehicle class pedelec is defined and will be registered in the official accident statistics in Germany. This makes an analysis regarding the accident situation of pedelecs possible in future. At this time, no reliable figures about the level of possible impact to accident situations are available but a first approach could be to analyze the traffic accident situations involving conventional bicycles with comprehensible assumptions respect to pedelecs.

Status

According to official statistics of 2012 [3] 74,961 accidents with causalities and bicycle involvement occurred. 406 users of bicycles were fatal, 13,840 riders were severely and 60,423 slightly injured. In about 41% of accidents with bicycle involvement (police reported, accident with casualties), the cyclist is the main causer. Approximately 83% of registered accidents with casualties and involved bicycles occur at daylight respectively at dry road conditions. Major registered faults within this category of bicycle riders in 2012 were identified as “wrong using road infrastructure" with almost 24% and "other driver's fault" with a share of 30%.

More information about the accident situation involving bicycles are not available in official statistics. Therefore an in-depth-analysis was done. The analysis of the GIDAS database[1] confirmed the interpretation of this official statistics by using the detailed specification of accident types. It is seen that the most common accident type are conflicts while crossing with a share of approximately 44% of these registered accidents. In addition 17% are characterized as cornering conflicts and 10% as accidents in longitudinal traffic. This is shown in Fig. 2.

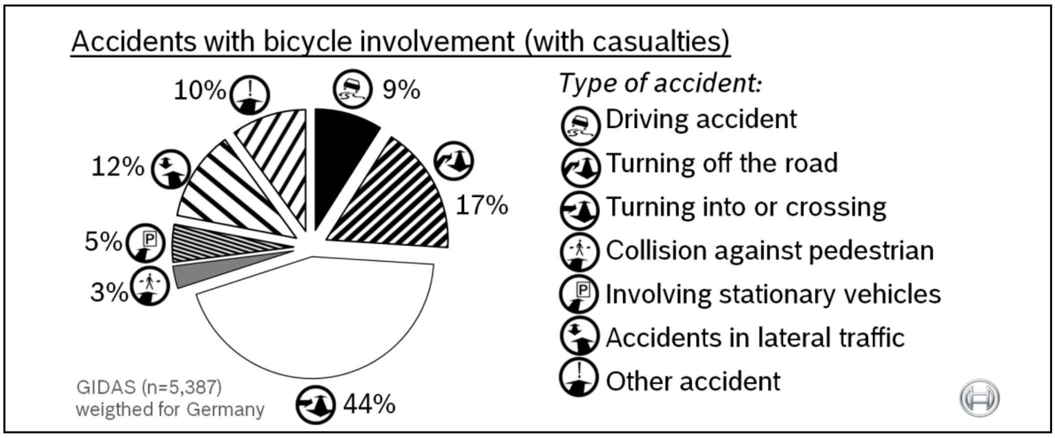


Fig. 2: Type of Accident, Accidents with bicycle involvement and casualties [4]

It is evident from Fig. 3, the highest share of accident causing situations with bicycle involvement and casualties is the accident type “Intersection, privileged cyclists from right on bicycle path” (but contrary direction of travel) coded as 342 with approximately 16%. Within this category the cyclists which used (often irregularly) the pedestrian walkways were neglected.

[1] 5,387 accidents with bicycle involvement – weighted for Germany

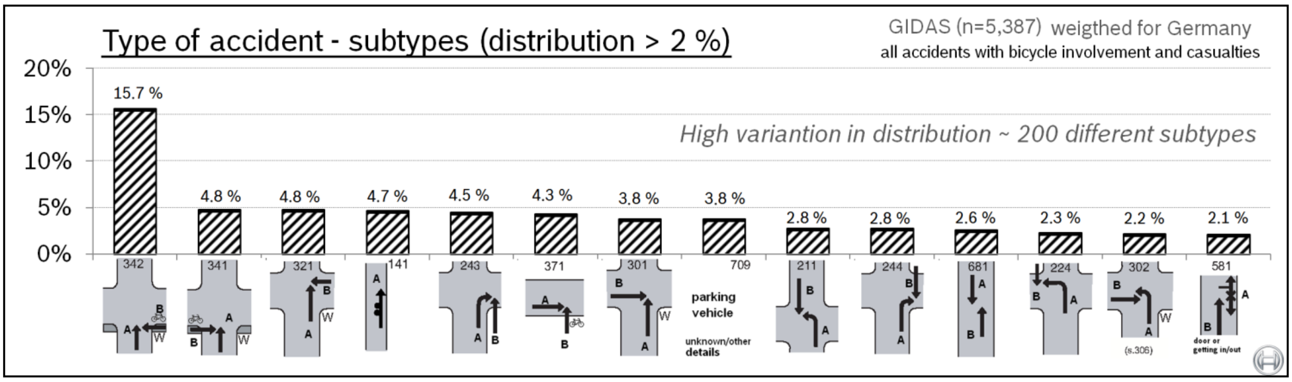


Fig. 3: Type of accident, subtypes with distribution greater than 2% [4][6]

Further on in 63% of all GIDAS accidents with bicycle involvement the opponent was a passenger car in the first collision. Bicycle to bicycle (11%) collision and direct contact with ground (12%) are also documented as first collision.

Research method

It is assumed that the general behavior of pedelec[2] user is similar to user of conventional bicycles. This is justified with the fact that a "normal" cyclist is able to reach nearly the same driving performance like a user of a pedelec if some more muscle power is considered. In particularly the maximum supported speed of a pedelec 25kph is reachable for a bicyclist without electrical support.

One intension of the study is, to show in how many situations an electrical support of bicycle has no influence to the sequence of accident events. Basis of the study are the in GIDAS database available accidents involving conventional bicycles. These accidents have been modified by a fictitious electrical engine support and thereby possible increasing speed. Afterwards the modified (pedelec) accidents have been compared with the original bicycle accident. The following assumptions were made in this individual case study:

- For Pedelec, the original speed of the bicycle (if possible) is increased by 10kph max as a pessimistic approach. The increasing of speed is only done in cases where this is possible due to the traffic situation.

- No change in precise positioning after recalculating of velocities (same collision point). The main reason for this assumption is the fact that in some cases the speed increase in initial situation results in a shift of the contact point. This means some collisions would not happened with a higher speed of pedelecs and on the other hand some former critical situations without collision (no accident – not in database) would result in an accident.

[2] Class 25kph, 250W only

Following basic assumptions are used for the analysis regarding pedelecs and their influence (possible change) in accident statistics of Germany:

- The distribution of accident types / kinds of accidents remains unchanged.
  At this point of time it is not possible to predict a change in driving behavior of pedelec users. Whether there will be a shift in the distribution of accident types, can only be clarified by an analysis of a representative number of real accidents with pedelec involvement. This will probably be possible with the introduction of the new class of vehicle in the official accident statistics. Due to the fact pedelecs are very similar to conventional bicycles, the assumption no change in distribution of accident types is chosen.

- The results regarding injury risk and projected total number of casualties for Germany are calculated for 5%, 10% share of pedelecs of all bicycles.

- Underreporting of single accidents is considered.
  Some current bicycle accident studies (e.g. in [9]) show that in Germany a number of underreported accidents (not in official statistics) with bicycle involved exists. In particular, this relates to bicycle accidents with injured bicyclists without property damage, for example a fall down or collision with a fixed object. These accidents are not often reported to the police and if necessary the involved bicyclists arrange the medical treatment by themself (usually in case of minor injuries only). Here the underreported bicycle accidents (with casualties) are considered with a double weighting of bicycle accident without second participant (single-vehicle accidents).

To answer the question, raised as intention of the study, it is necessary to examine each individual accidents in the database. The analysis of all accidents is not possible due to the high number of relevant accidents. The for the study needed single-case analysis is done with 522 bicycle accidents in GIDAS. This choosen subsample includes all bicycle accidents in GIDAS in the year of 2009 (latest available complete year). The evaluation of a complete year ensures the consideration of different user behavior with different weather conditions, days of the week and seasonal issues. The preliminary analysis (distribution accident types, injury severity in terms of speed) was done with the maximum number of cases in GIDAS (2001-2012). Further on it was ensured that the accident type distribution belongs to the official statistics therefore a representative GIDAS subsample was analyzed. Fig. 4 gives an overview of the analysis in principal.

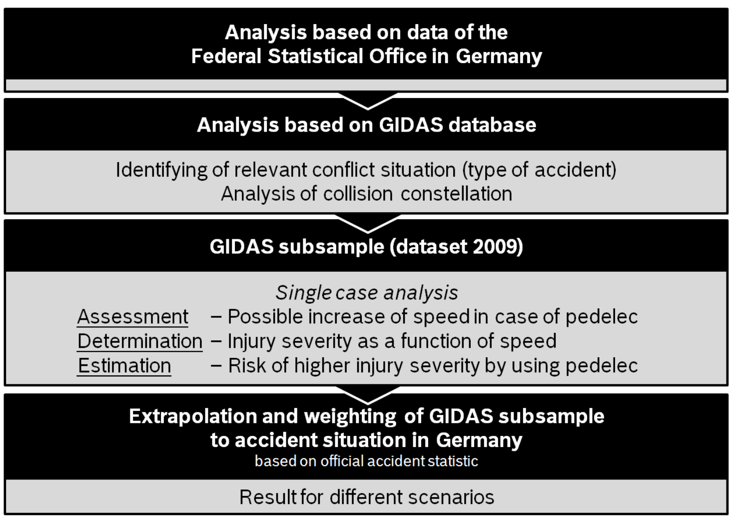


Fig. 4: Methodology of the study

Results

Apart from other accident related factors the important parameter is collision or initial speed of the bicycle which links directly to the severity. In single-case analysis it is evaluated whether a higher speed of pedelec instead of bicycle is possible. Main factors are the traffic situation and road condition at the accident scene. For this purpose, the detailed reconstruction data including scaled sketch, accident descriptions and pictures were used.

Taking into account that the electrical support in case of a pedelec is given up to 25kph one major result is shown in Fig. 5.

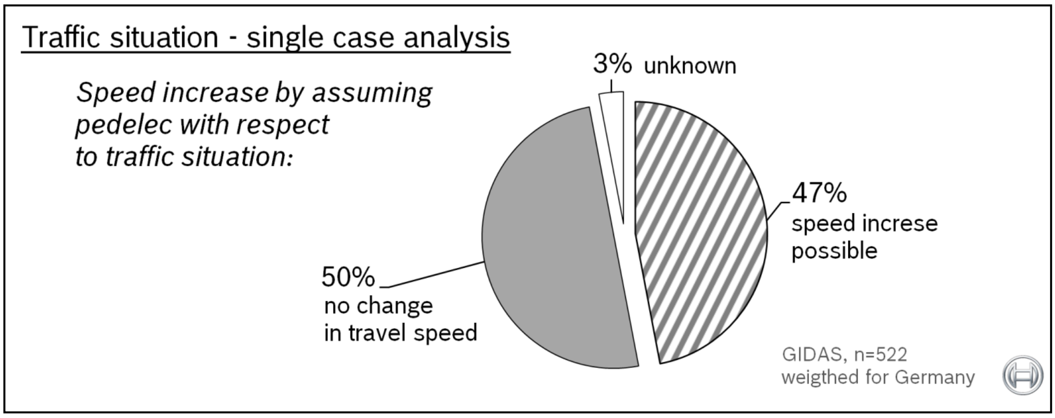


Fig. 5: Single case analysis of traffic situation by assuming pedelec instead of bicycle [4]

In around half of the registered bicycle accidents, a higher initial/travel speed is not possible hence a change is not assumed. This result is mainly caused by driving situation and the fact that a higher travel speed with respect to the situation is not possible. These situations are e.g. while turning into a road, driving down the hill and while waiting. Detailed reasons are shown in Fig. 6.

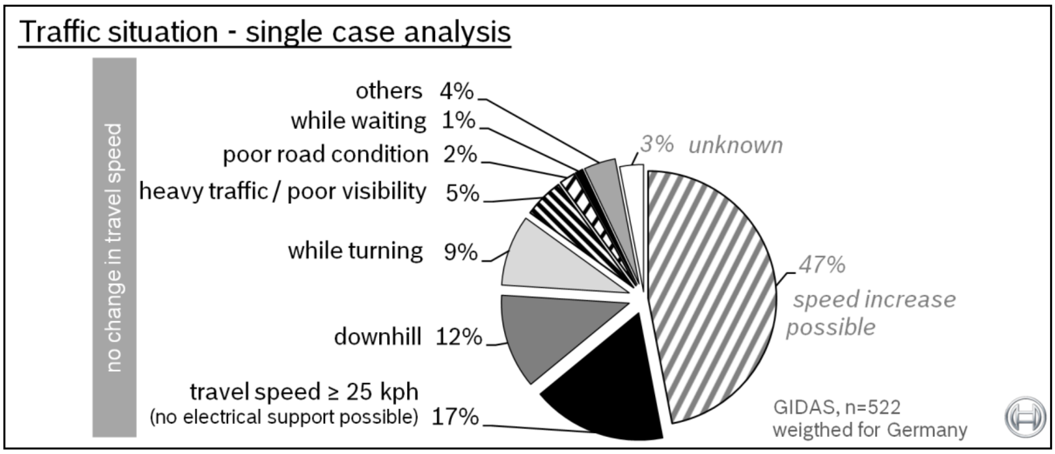


Fig. 6: Single case analysis, Reasons for no change in travel speed [4]

A higher speed is therefore assumed while driving on free roads (45%) or while a support is given during hill driving (2%).

In addition to the traffic situation with possible increased speed, the collision situation itself has influence to the injury consequences of cyclists. For the consideration of these crash details all accidents are divided in four groups describing the collision situation according to the following definition:

Group 1: Fall down or collision with an object (mainly single-vehicle accidents)
Group 2: Collision with other vulnerable road user (pedestrian, bicycle, motorcycle)
Group 3: Bicycle hit a vehicle (car, truck or bus), bicycle frontal contact
Group 4: Bicycle was hit by a vehicle (car, truck or bus), bicycle side or rear contact

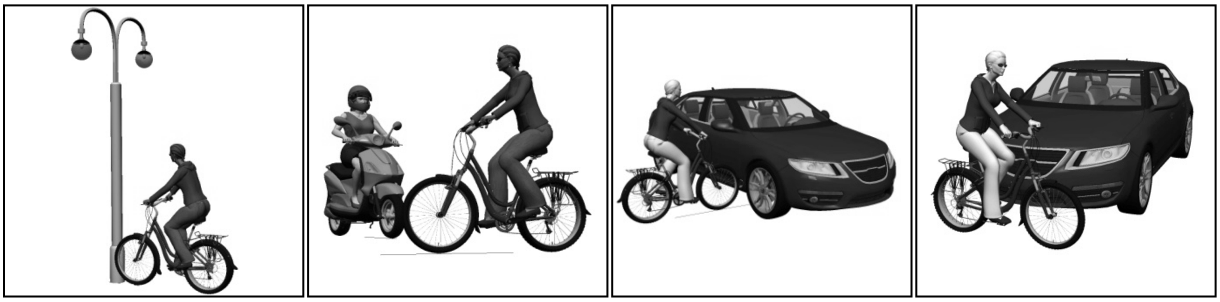


Fig. 7: Animated situations for Group 1 (left) to Group 4 (right)

The classification is done due to the fact that in Group 1-3 the speed of the cyclist (and therefore the pedelec) is more relevant for its severity. Contrary to the groups 1-3 in group 4 the speed and also the mass of the opponent are the main important factors regarding the severity of cyclists. The initial speed of bicycle has only a minor influence.

The following collision situation distribution is given (Fig. 8). Every third bicycle accident (32%) results in a contact against an object or fall down without another primary impact (Group 1). In a share of 13% a conflict between a bicycle and other vulnerable road user is given (Group 2). Further on in about 16% of all analyzed bicycle accidents, the cyclists hits another vehicle (car, truck or bus) with the bicycle front (Group 3).

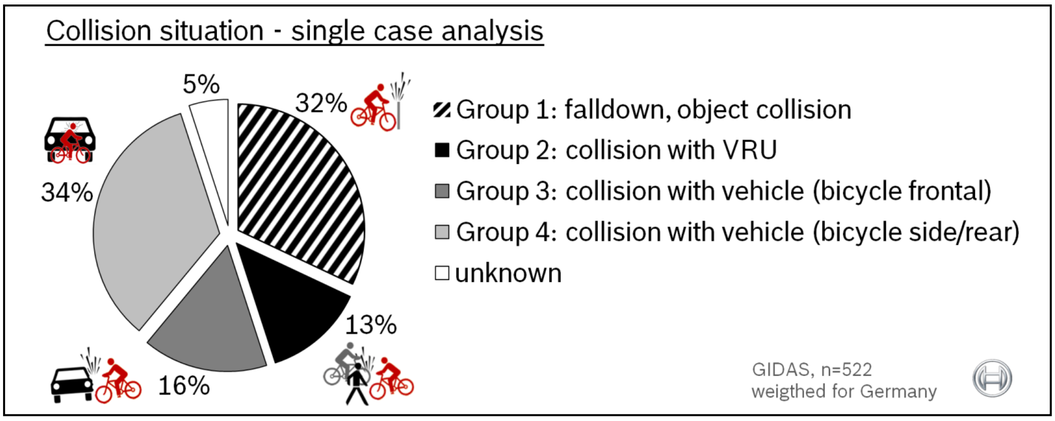


Fig. 8: Single case analysis, Collision situation [4]

The highest share of 34% is categorized in Group 4 whereas a vehicle (car, truck or bus) hits the side or the back of the bicycle. These accidents are characterized with a higher severity of the cyclists. In those accidents the bicycle speed can be neglected due to the fact that the collision speed of the motorized vehicles is the main contributing factor for the injuries at time of collision. Unfortunately, the mass of the vehicle is much higher compared to the bicycle. In another share of about 5% the accident details are unknown and therefore not considered in the analysis.

To determine the possible change in the severity of the current accident situation (number of severe injured persons), it is necessary to combine the results shown in Fig. 5/Fig. 6 with results shown in Fig. 8. Linking single case analysis regarding traffic situation with the collision situation results in a share of 27% of all accidents where a higher travel speed could be assumed. In other words in 68% of all relevant accidents, no higher risk of injury severity in case of using a pedelec is seen because of speed has no higher influence or a higher speed is not possible as result of the traffic situation. This distibution is shown in following Fig. 9. Only the collision situation of group 1, 2 and 3 with a possible speed increase have a higher risk in injury severity.

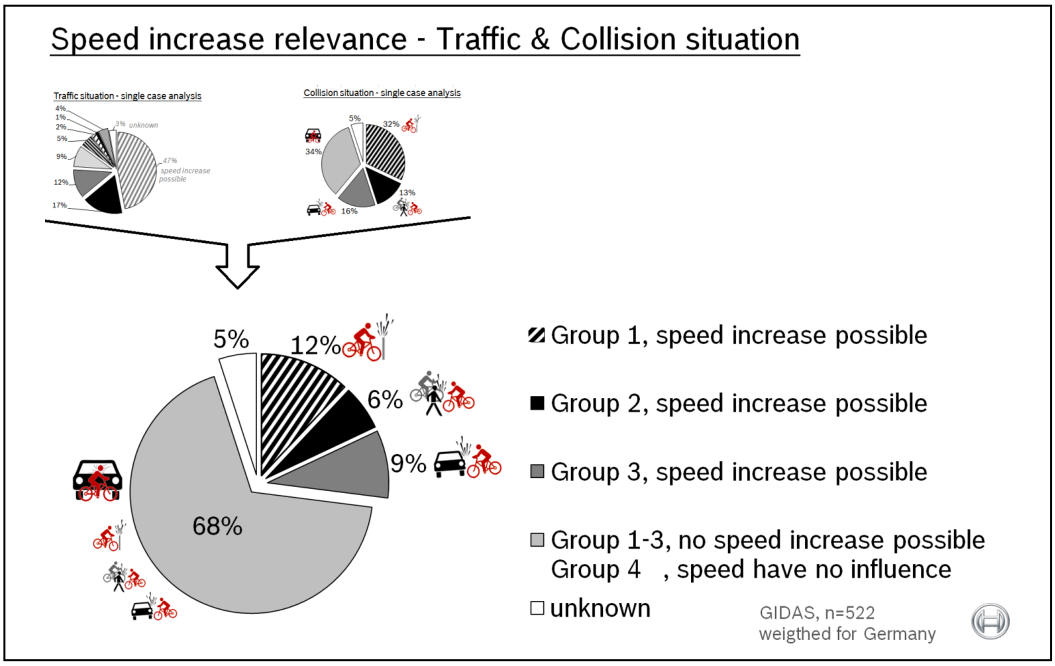
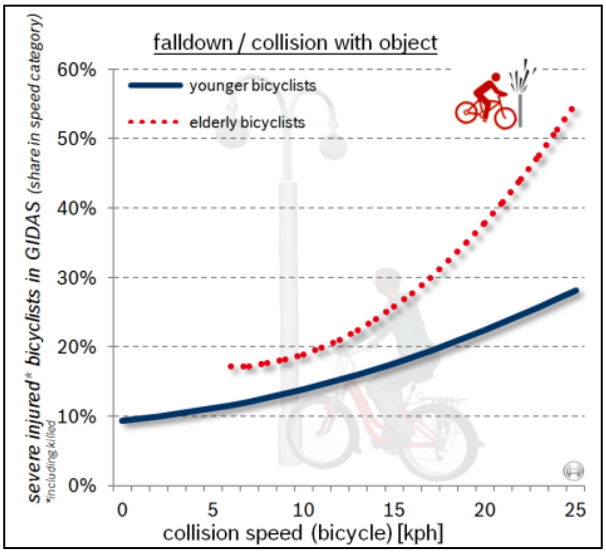


Fig. 9: Results of combination of traffic situation and collision situation [4]

To determine the possible influence to German accident situation, the injury severity was recalculated for each relevant GIDAS accident. The results are weighted and projected to Germany. The categories of injury severity was determinated in the two groups ("slightly injured" and "severe/fatal injured"). Due to the fact of low count of relevant cases with fatal injured cyclists in GIDAS a further differentiation in "severe injured" and "killed" is not useful. The analysis of injury severity with respect to collision speed was done for two age groups (younger bicyclists age <50, elderly bicyclists with age 50+).

The risk of being severe injured as a user of pedelec is recalculated for each relevant case as a function of speed (including max. 10kph speed increase), age and collision details. As a basis the determined[3] functions of all bicycle accidents in GIDAS were used. The following figures show the distribution of severe injured bicyclists in percentage for each group of collision situation (Fig. 10, Fig. 11, Fig. 12 and Fig. 15).

[3] Polynomial regression of all bicycle accident in same speed and age category



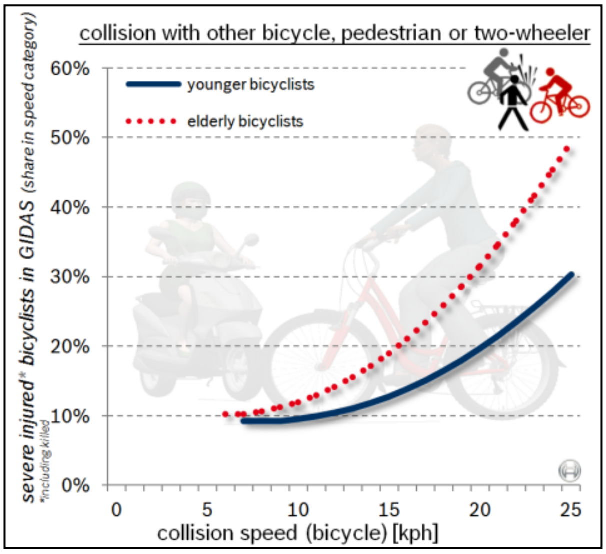


Fig. 10 (left): Dependance of injury severity to bicycle collision speed for collisions situation of group 1

Fig. 11 (right): Dependance of injury severity to bicycle collision speed for collisions situation of group 2

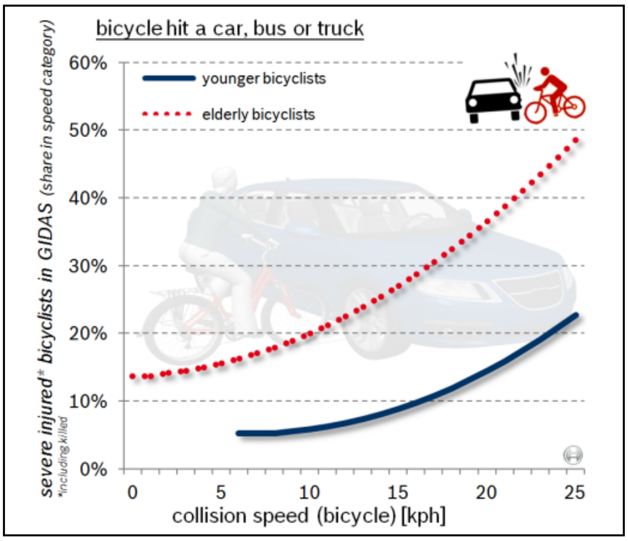


Fig. 12: Dependance of injury severity to bicycle collision speed for collisions situation of group 3

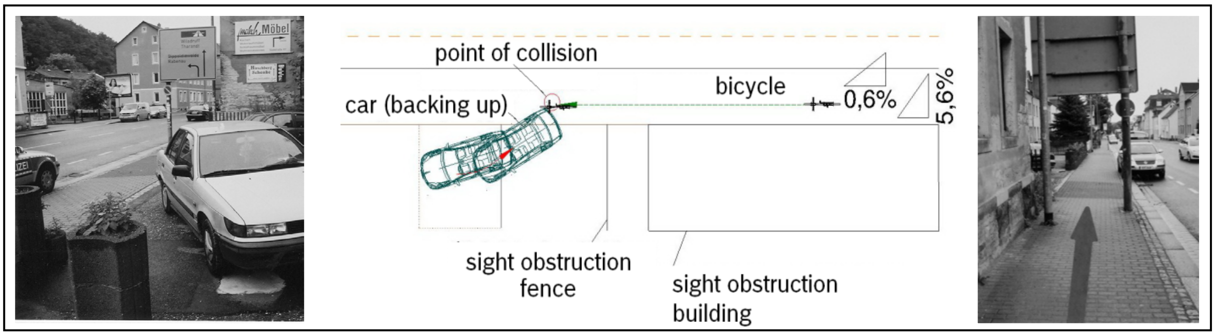


Fig. 13: Example case (1090437), collision situation of group 3 with possible speed increase

In the example-case (see Fig. 13) The bicycle hit a car which drove backwards. The collision point was located at the frontal tire of the bicycle. As result the case is dedicated to collision group 3 (Fig. 12). The reconstruction made by GIDAS experts calculated a speed of 12 kph (collision and travel speed, no braking reaction). In this study, with assumption of using a pedelec, the case was recalculated by using a increase collision speed (+ 10kmp) whitch results in a higher risk to be severe injured (Fig. 14).

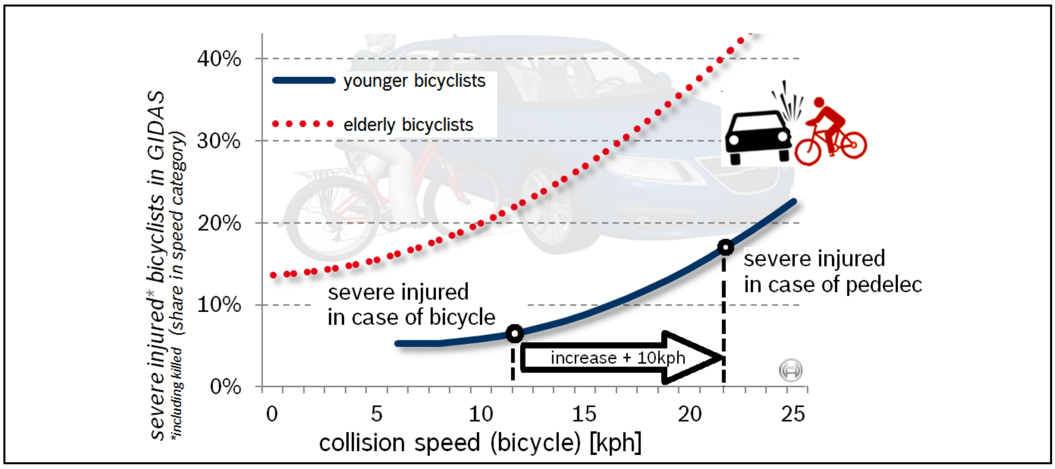


Fig. 14 : Change in injury severity by using pedelec instead of bicycle (Example)

In the case of using a pedelec the electrical support is only up to 25 km/h. In accident situations with higher speed the original injury severity is used. Also in all cases with collision situation of group 4 no changes were considered because the main factor is the collision speed of the motorized vehicle. The graph shows impressively the big influence of vehicle speed but has no influence regarding pedelecs.

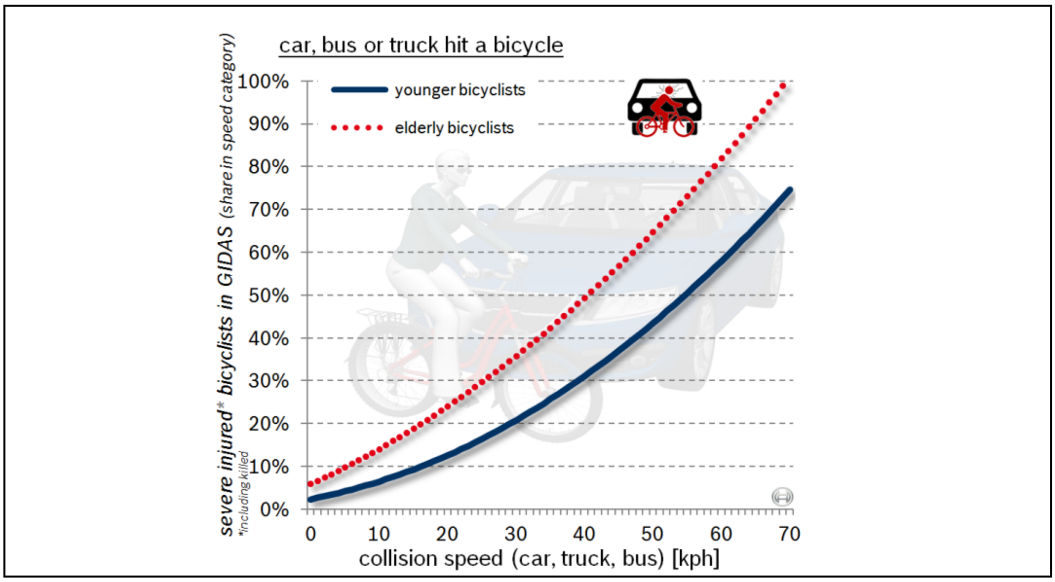


Fig. 15: Dependance of injury severity to vehicle collision speed for collisions situation of group 4

Conclusion

The study shows, in many real situations (68%, see Fig. 9) an electrical support of bicycle has no influence to the sequence of accident events. Taking into account a number of unreported "single bicycle accidents", the adoption of similar traffic behavior and similar age distribution, we determined a shift of 400 former slightly injured to seriously[4] injured cyclists in Germany per year. In Overall this would be an increase of approximately 2.3% in case of 10% of pedelec penetration with the assumption of 10 kph speed increase (if possible).

Analysis of bicycle accidents with exploration to pedelecs shows contrary to popular opinion (strong increase in serious accidents) the number of higher injured cyclists rises only moderately (per year around 400 additional).

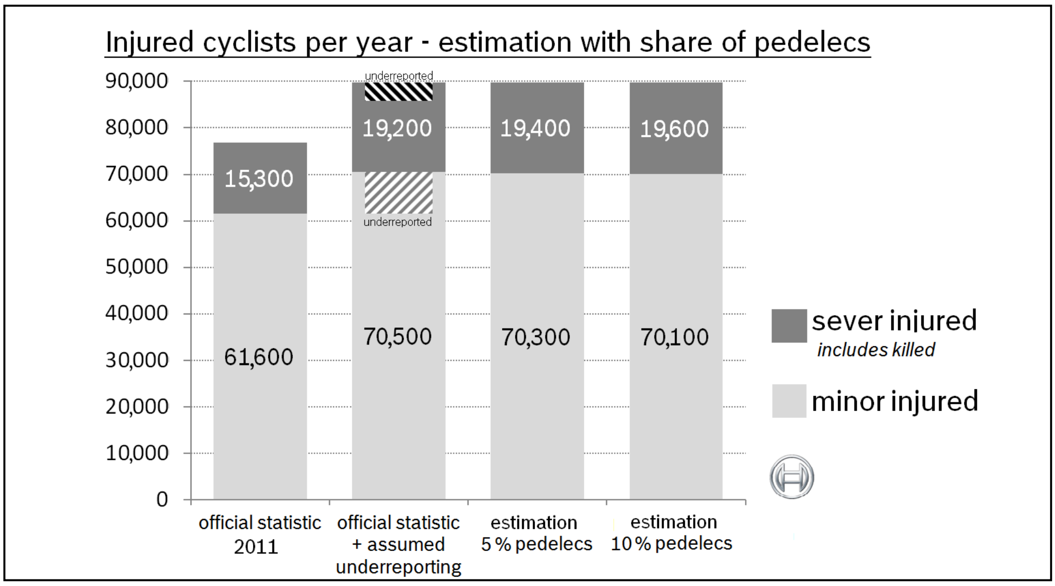


Fig. 16: Injured cyclists per yer with considering a share of pedelecs and underreported single accidents

For this study, a pessimistic approach by using speed increase of 10 kph was chosen, but first running natural driving studies predict a much lower increase in average speed of pedelecs [8]. The general opinion "the possibility of higher speed causes in large increase in severe accidents" is also not seen (Fig. 17) in the current existing official categories of two-wheeler (bicycle, moped (max. 25kph) and small motorcycles (max. 45kph).

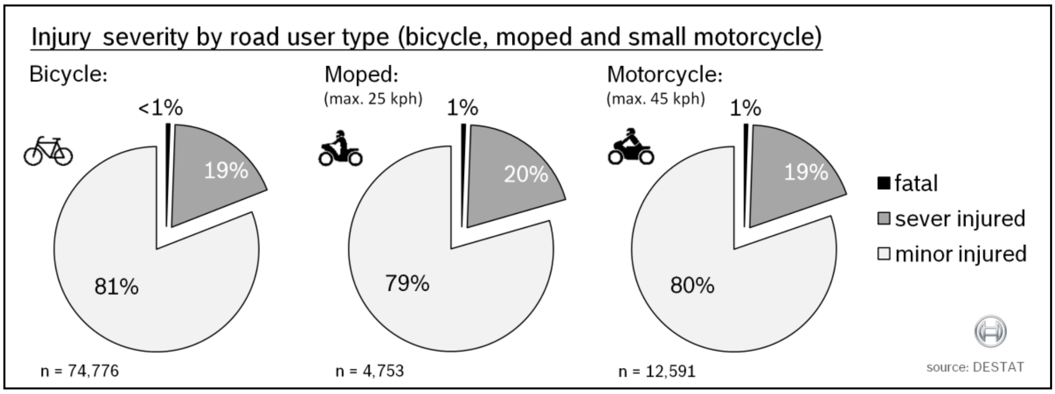


Fig. 17: Distribution of injury severity of different two-wheeler categories

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[4] In few cases also fatal

Reasons for the similarity of these vehicle classes may be the increasing safety awareness (e.g. use of protective clothing, better traffic discipline) and also a better visibility for other road users (noticeable driving behavior, no driving on walkway). In case of pedelec, the possible increase of severe injured cyclists could be compensated by other safety systems such as improved protective clothing, helmet or high quality brakes.

The hypothesis verbalized in the initial question *"Did a higher distribution of pedelecs results in more severe accidents in Germany?"* is not verified. This study shows, electrical support didn't result in higher collision speed in general. In many accident situations, the speed of pedelec have only a minor influence with respect to the accident severity. Further research focusing a possible change of driver behavior especially in new target groups (elderly people) is also needed.

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Analysis of pedestrian accident leg contacts and distribution of contact points across the vehicle front

A Barrow*, C Reeves*, J A Carroll*, R Cuerden*,
H Liers**, M Marschner** and P Broertjes***

*TRL Limited, Wokingham, Berkshire, RG40 3GA, UK
**VUFO (Verkehrsunfallforschung an der TU Dresden GmbH), Semperstraβe 2a, 01069 Dresden, Germany
*** European Commission, DG Enterprise and Industry, Automotive Industry Unit, B-1049 Brussels, Belgium

Abstract - Determining the risk to pedestrians that are impacted by areas of the front bumper not currently regulated in type-approval testing requires an understanding of the target population and the injury risk posed by the edges of the bumper. National statistics show that approximately 10% of all accident casualties are pedestrians, with 20% to 30% of these pedestrian casualties being killed or seriously injured. However, the contact position across the front of the bumper is not recorded in national statistics and so in-depth accident databases (OTS, UK and GIDAS, Germany) were used to examine injury risk in greater detail. The results showed that some injury types and severities of injuries appear to peak around the bumper edges. Although there are sometimes inconsistencies in the data, generally there is no evidence to suggest that the edges of the bumper are less likely to be contacted or cause injury.

INTRODUCTION

Throughout the world each year, thousands of pedestrians and cyclists are struck by motor vehicles. In most countries, including those of the European Union (EU), pedestrians and other vulnerable road users form a significant proportion of all road user casualties. Measures to improve car design, to mitigate pedestrian injuries in collisions, are effective in reducing injury risk measures in physical testing and are assumed to be effective in reducing the number of fatalities and serious injuries [1]. While the number of pedestrian injuries and fatalities continues to decline, year on year, within the EU, it is not decreasing as quickly as the decline in total traffic fatalities [2].

Fractures to the shaft of the tibia are the second most commonly observed primary injury for pedestrians recorded in the Hospital Episode Statistics (HES; [3]). Whilst simple fractures of the long bones may generally be expected to have a good prognosis, fractures involving multiple regions of both lower limbs are associated with a very long duration of stay in hospital (mean of 33.9 days). Consequently, lower limb injuries sustained by pedestrians may not be the most costly on an individual basis but their high rate of incidence means that they are by far the most costly based on hospital admissions. The estimated annual cost for lower limb injuries in England was over £14.5 million [3].

The most frequent cause of all leg injuries in car-pedestrian accidents is contact with the front bumper. Therefore, this is the most important cause of non-minor leg injuries [4]. Contact with the ground is the second most frequent cause of leg injuries, although the vast majority of these are likely to be minor injuries.

In order to sell a vehicle in Europe, manufacturers must be granted vehicle type-approval by passing a series of tests set out in Annex I of the Commission Regulation. The tests are based on three principal procedures, each using different sub-system impactors to represent the main phases of a car-to-pedestrian impact. The three impactor types are:

- A legform impactor representing the adult lower limb
- An upper legform impactor representing the adult upper leg and pelvis
- Child and adult headform impactors

Each impactor is propelled into the car and the output from the impactor instrumentation is used to establish whether the energy-absorbing characteristics of the car are acceptable. A minimum of three legform to bumper tests are required, one to each section of the bumper when divided into equal thirds (Figure 1). The outer third test points have to be a minimum of 66 mm (the nominal radius of the EEVC legform) inside the defined corners of the bumper to ensure that the full contact region is within the area defined between the bumper corners.

Figure 1. Bumper tests are divided into thirds for three tests

The area to be assessed in the legform to bumper test is specified in Commission Regulation (EU) No. 631/2009. The corner of the bumper is determined through the following definition:

> "… the vehicle's point of contact with a vertical plane which makes an angle of 60° with the vertical longitudinal plane of the vehicle and is tangential to the outer surface of the bumper."

The level of pedestrian protection may be degraded from the original intent of the legislation. If vehicle manufacturers produce vehicles where the defined corner of the bumper is a substantial distance from the side of the vehicle, the testable area can be significantly reduced. In extreme cases, the testable area can be as little as 40 % of the full frontal width of the car [2]. Assuming that pedestrians can be struck by any part of the vehicle front then there could be degradation in safety levels if the tested area is now smaller than it has been in the past.

Previous research regarding pedestrian contacts with vehicle bumpers has assumed an equal distribution of impact points across the width of the vehicle front. If, instead, there was an increased risk of contact towards the edge of the bumper then it may have important consequences for the effectiveness of a change to the corner definition. To investigate this assumption accident case data from the UK and Germany have been reviewed.

METHODOLOGY

Although the national accident datasets such as STATS19 and CARE can provide an indication of the target population (i.e. pedestrians hit by the front bumper of cars), information about the location on the bumper where the pedestrian struck the vehicle is not available. In depth accident studies such as On-The-Spot (OTS) in the UK and German-In-Depth-Accident-Study (GIDAS) in Germany provide detailed information on a small, but representative, sample of the road accidents to help understand the accident situation in more detail. Specifically, where on the bumper are pedestrian casualties struck and if there is a difference in this distribution by age, sex or movement of the casualty, speed or registration year of the vehicle. Each accident case is also supplemented with detailed medical records of the injured parties. This was used to analyse injury severity with contact distribution across the bumper and the risk of injury outside the testable area of the bumper. The sampling plans and sample areas chosen in both the GIDAS and OTS studies ensured that the accident data was representative of the accidents severities and approximated the distribution of accidents occurring on a national scale.

The initial hypothesis stated there was an equal probability of a pedestrian being struck across the length of the bumper. If the distribution is not uniform, then the second part of the hypothesis was that the relationship is linear, approximately. This arises from the fact that pedestrians are more likely to be hit by a vehicle when crossing from the nearside of the vehicle as the car driver has less time to see the pedestrian before the point of impact. The data were then broken down by injury type and severity to determine if there is a greater risk of injury at the outskirts of the bumper compared with the centre or if injury risk is also linear across the bumper.

OTS sample

The OTS accident data collection study gathered in-depth information on over 4,700 road traffic accidents from two distinct geographical areas between 2000 and 2010. Filtering the database for a suitable sample of pedestrian accidents resulted in a total of 232 pedestrian accidents out of 304 total pedestrian cases.

The following exclusion criteria were then applied:

- The pedestrian was struck by the side of the vehicle, side swiped or the pedestrian ran into side of vehicle;
- The vehicle was stationary and the pedestrian collided into the vehicle;
- The vehicle reversed over the pedestrian;
- The pedestrian was not impacted by the front of the vehicle.

This resulted in 116 relevant pedestrian accident cases for analysis each with 1 pedestrian involved. The point of contact where the pedestrian was struck on the vehicle's bumper was divided into five equal segments stretching across the full width of the bumper. These segments are displayed as percentage ranges of the vehicle width starting from 0% to 100% from the offside to the nearside (see Figure 2). This was determined using a combination of vehicle and pedestrian paths, case summary, recorded evidence and vehicle photos from the OTS database. The segments are labelled the other way around for GIDAS as vehicle drive on the other side of the road in Germany.

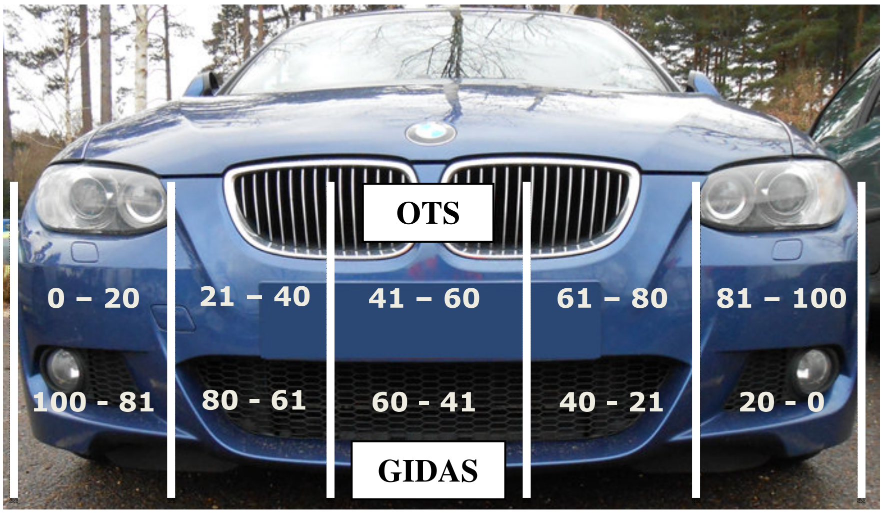

Figure 2. Contact point is divided into five equal segments across the bumper displayed as percentages of the vehicle width (OTS percentages are on top, GIDAS underneath).

GIDAS sample

This study is based on the GIDAS dataset available from January 2013. Currently there are 23,444 reconstructed accidents from both investigation areas Dresden and Hanover. 27,690 passenger cars were involved in these accidents. In 2,271 accidents a car hit a pedestrian. 758 pedestrians had their first contact with the legs on the bumper. Pedestrians whose exact contact point location could not be determined were excluded from the dataset.

The information recorded in the GIDAS database allowed a higher degree of precision in determining the pedestrian contact point on the bumper and so the bumper was divided into 10 segments of the vehicle width, but for comparison with the OTS data the data was grouped in to 5 segments. The segments are also labelled 0% to 100% from the offside to the nearside of the vehicle front (Figure 2).

Statistical analyses

To assess the first hypothesis, a chi-squared goodness-of-fit test was used (Tables 1 and 2). This tests for a difference between the numbers of casualties struck in each of the contact positions and the theoretical number if the distribution of contact positions was uniform across the bumper.

The second part of the hypothesis was tested using a linear regression which will indicate if the probability of pedestrian contact position across the front bumper can be described as a linear relationship (Figures 3 and 4).

Statistical analysis of the injury risk was not possible due to low sample numbers in both the OTS and GIDAS datasets. Instead, the datasets have been broken down into injury types and severities across the bumper sections and observations made on the results (Tables 3 to 8).

RESULTS

All of the results are presented against the contact position on the front bumper as per Figure 2. It is important to note that the segments across the bumpers have been labelled so that 0-20% is always the offside of the vehicle and 81-100% is the nearside to the kerb for both datasets.

Contact distribution

Table 1 and Table 2 show the number of OTS and GIDAS cases by contact position across the bumper. The chi-squared test of the hypothesis (excluding those with unknown contact position) shows that the distribution of casualties across contact position groups is not significantly different from that of a uniform distribution for the OTS sample ($p = 0.11$).

Table 1. Number of OTS cases by contact position across the bumper

Contact position	Number of casualties
0-20	18
20-40	14
40-60	23
60-80	22
80-100	31
Unknown	8
Total	116

The chi-squared test for the GIDAS sample shows that the distribution of casualties across categories of contact position is significantly different from that of a uniform distribution ($p < 0.05$).

Table 2. Number of GIDAS cases by contact position across the bumper

Contact position	Number of casualties
0-20	113
20-40	130
40-60	168
60-80	166
80-100	181
Total	758

The second part of the hypothesis has been tested in Figure 3, which shows the distribution of casualties across contact points of the bumper in the OTS sample; a line of best fit is included. Figure 4 shows the equivalent data from the GIDAS sample. The R^2 value (a measure of the variance explained by the linear regression model) is also shown.

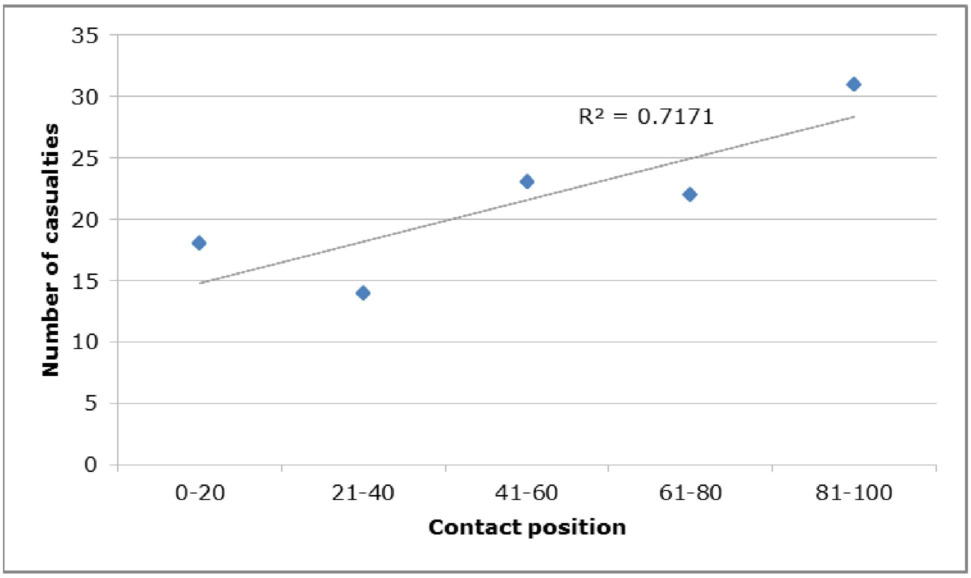

Figure 3. Distribution of casualties across contact points of the bumper (OTS)

Figure 3 shows that more pedestrian casualties were struck between contact positions 81-100 (i.e. the nearside of the vehicle in the UK) than those struck by the offside. The regression line demonstrates that the contact position explains 71% of the variability in the number of casualties. The linear trend between number of casualties and contact position seems a reasonable approximation in this instance.

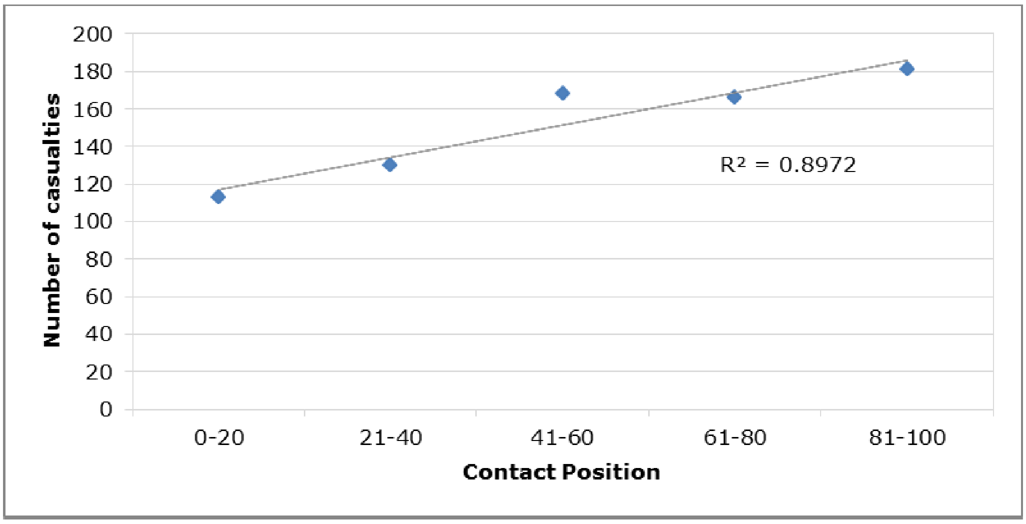

Figure 4. Distribution of casualties across contact points of the bumper (GIDAS)

Figure 4 shows that more pedestrian casualties were struck by the nearside of the vehicle than those struck by the offside. The regression line shows the contact position explains approximately 90% of the variability in the number of casualties. Therefore, the relationship between contact position and number of casualties in the GIDAS can be approximated as being linear.

Injury risk

The next part of the analysis aims to determine if there is a greater risk of injury at the outskirts of the bumper compared with the centre or if injury risk is also linear across the bumper. Injury severities have been coded using the Abbreviated Injury Scale (AIS). It should be noted that the GIDAS MAIS is based on the AIS 1998 edition, whereas the OTS MAIS was a mixture of AIS 1990 and 2005, but for simplicity is presented here based on the 1990 coding. This is not expected to alter the general impressions provided by the data in Tables 3 and 4, substantially.

In the first instance, the whole-body Maximum AIS score (MAIS) for each pedestrian was considered. This gives an overall indication of the severity of the accident for the pedestrian. The results from the OTS sample and GIDAS are shown in Tables 3 and 4.

Although sample numbers are relatively low in both datasets, the data indicate that approximately 90% of pedestrians incur injuries of a maximum severity of MAIS 3 or below and the most severe injuries are relatively uncommon. These data also show that severe MAIS 4, 5 or 6 casualties can be caused by contacts from any fifth of the vehicle front in both datasets. Furthermore, less severe injuries with MAIS 1, 2 or 3 can also occur at any point along the bumper front but they appear to have a similar distribution to the contact position with slightly more injuries occurring at the nearside of the vehicle, in general.

Table 3. Number of OTS cases by whole-body MAIS and contact position

	Contact Position							
MAIS	Unknown	0-20	21-40	41-60	61-80	81-100	Total	% Total
0	3	2	2	2	4	4	17	14.7
1	3	8	7	9	6	8	41	35.3
2	1	5	2	8	2	6	24	20.7
3	1	2	0	2	3	8	16	13.8
4	0	0	1	1	4	1	7	6.0
5	0	0	0	1	2	1	4	3.4
6	0	0	0	0	0	0	0	0.0
9	0	1	2	0	1	3	7	6.0
Total	8	18	14	23	22	31	116	

Table 4. Number of GIDAS cases by whole-body MAIS and contact position

	Contact Position						
MAIS	0-20	21-40	41-60	61-80	81-100	Total	% Total
0	0	0	0	0	0	0	0.0
1	15	19	26	24	21	105	43.0
2	20	12	11	20	25	88	36.1
3	2	3	1	2	5	13	5.3
4	2	3	2	1	3	11	4.5
5	1	1	1	4	1	8	3.3
6	0	2	0	0	3	5	2.0
9	2	3	4	0	5	14	5.7
Total	42	43	45	51	63	244	

The GIDAS database allows injuries to be assigned to an injury causing vehicle part. Therefore it is possible to look at the maximum AIS of the lower extremity injuries caused by the bumper (Table 6). An equivalent analysis of the OTS sample was not possible, therefore all lower extremity injuries are considered regardless of the contact causing the injury (Table 5). The advantage of doing this with the GIDAS data is that injuries caused as the pedestrian was thrown to the ground are excluded. The injuries reported are thought to have been caused by the primary interaction with the vehicle bumper by the investigators at the scene of the accident. This exclusion of alternative injury sources is not available for the OTS data.

Tables 5 and 6, show the numbers of injuries in the OTS and GIDAS samples, grouped according to the contact position as well as the part of the lower extremity which sustained the injury. Despite low sample number, the OTS dataset shows the lower leg is the body region with the most frequent injuries, but has a clear peak in the centre section of the bumper. While the majority of injuries have an unknown or unclassifiable body region and appear to be slightly more frequent in the nearside sections (61-80% and 81-100%) of the bumper. The total number of injuries also appears to follow the trend of being skewed towards the nearside bumper sections.

The lower leg is by far the most frequently injured body region of the lower limb in the GIDAS dataset, followed by the knee. The frequency of injuries in the lower leg, and to a certain extent the knee, demonstrate a skew to the nearside sections of the bumper (61-80% and 81-100%). This is also apparent in the total injuries to all body regions of the lower leg which demonstrates the same skew as the OTS total injuries. However, both datasets also show that injuries to the lower leg and other regions can occur across the bumper width.

Table 5. Number of OTS injuries by body region and contact position for all injury severities

	Contact Position						
Body Region	Unknown	0-20	21-40	41-60	61-80	81-100	Total
whole leg	0	0	0	0	0	0	0
upper leg	0	1	0	1	3	4	9
knee	0	3	0	1	2	2	8
lower leg	1	3	7	11	4	7	33
ankle	0	0	0	1	0	0	1
foot	0	0	0	0	1	4	5
unknown or unclassifiable region of the leg	5	14	15	23	29	35	121
Total	6	21	22	37	39	52	177

Table 6. Number of GIDAS injuries (caused by bumper contacts only) by body region and contact position for all injury severities

	Contact Position					
Body Region	0-20	21-40	41-60	61-80	81-100	Total
whole leg	0	0	0	0	1	1
upper leg	2	4	3	2	3	14
knee	8	17	11	15	15	66
lower leg	16	25	23	34	35	133
ankle	1	1	0	2	2	6
foot	0	4	1	2	5	12
unknown or unclassifiable region of the leg	1	2	3	0	2	8
excluded (hip or pelvis)	1	1	0	0	0	2
Total	29	54	41	55	63	242

The previous two tables included injuries of all severities to each of the various parts of the lower extremity. However, the injuries occurring most frequently in hospital admissions and likely to lead to the greatest burden of disability and cost are AIS 2 injuries to the knee and lower leg [3]. To investigate these injuries specifically, the breakdown of number of injuries by contact point and region of the lower extremity injured was limited to AIS 2 injuries only. These results are shown in Tables 7 and 8.

The majority of the lower leg injuries in the OTS dataset are AIS 2 severity so the distribution of injuries to this body region still reflects the peak in the centre sections of the bumper seen in the total injury distribution in Table 5. The other body regions of the lower limb have very few sample numbers in Table 7. The GIDAS dataset still contains primarily lower leg, and some knee injuries, and maintains the higher frequency towards the nearside of the bumper which is also reflected in the distribution of total injuries across the bumper (Table 8).

Table 7. Number of OTS injuries by body region and contact position for AIS 2 injuries

	Contact Position						
Body Region	Unknown	0-20	21-40	41-60	61-80	81-100	Total
whole leg	0	0	0	0	0	0	0
upper leg	0	0	0	0	0	0	0
knee	0	3	0	1	1	2	7
lower leg	1	2	5	11	4	7	30
ankle	0	0	0	1	0	0	1
foot	0	0	0	0	0	4	4
unknown or unclassifiable region of the leg	0	0	0	3	0	1	4
Total	1	5	5	16	5	14	46

Table 8. Number of GIDAS injuries by body region and contact position for AIS 2 injuries

	Contact Position					
Body Region	0-20	21-40	41-60	61-80	81-100	Total
whole leg	0	0	0	0	1	1
upper leg	0	0	0	0	0	0
knee	3	3	2	2	3	13
lower leg	7	10	10	21	16	64
ankle	0	0	0	0	0	0
foot	0	1	0	0	0	1
unknown or unclassifiable region of the leg	1	0	0	0	0	1
excluded (hip or pelvis)	0	0	0	0	0	0
Total	11	14	12	23	20	80

DISCUSSION

Both datasets display a linear relationship of contact point distribution skewed towards the nearside of the vehicle. The contact point distribution of the OTS dataset is not statistically different from a uniform distribution; however, this may be a consequence of a small sample size. It is close to being significant at the 90% confidence level and the linear regression suggests that the relationship is not uniform as well as linear.

Although the contact distribution is skewed, the linear relationship means that the risk of contact across the bumper is equal, assuming a symmetrical design of the vehicle's bumper and substructures. The increased risk to the nearside is cancelled out by the reduced risk mirrored on the offside in both datasets. This assumes that either the vehicles are symmetrical in design or that any asymmetry doesn't affect the risk of injury from the impact. It also takes a broad approximation of the contact point data, where a larger dataset could show small deviations from this approximation to be more important. However, bumper design can vary with certain vehicles that have offset licence plates such as the Alfa Romeo MiTo and most vehicles will have a tow-eye present on one side underneath the bumper.

The low sample sizes of the datasets prevent any statistical analysis of the data, instead, observations on the trends in the data can provide useful conclusions, although less robust. The data in Tables 3 and 4 seem to support the assertion that, whilst relatively uncommon, MAIS 4, 5 or 6 casualty severities can be caused by contacts from any fifth of the vehicle front. Unfortunately, the sample size is not large enough to determine whether a particular region of the vehicle width is more likely to cause these injuries than other regions.

MAIS 1, 2 or 3 pedestrian injuries seem to follow the same trend as the overall number of casualties, with a greater proportion occurring from contacts to the nearside than to the offside. There doesn't appear to be any one region which causes such injuries much more than would be expected based on an equal risk of injury across the whole vehicle width. Any MAIS severity of casualty injury can seemingly be caused by any fifth of the vehicle front.

Considering the contact distribution data with the region of the leg that was injured (Tables 5 and 6), gives an indication as to whether any region of the vehicle offers a substantially more injurious contact for the pedestrian lower extremity than another. Based on the results it can be observed that upper leg, knee, lower leg, ankle and foot injuries can be caused by a contact in any of the five fifths of the vehicle front.

Again, in Tables 7 and 8, it is evident that AIS 2 injuries can be caused through contacts with any fifth of the vehicle front. In the context of a bias in injury occurrence towards the nearside of the vehicle, it is not obvious that any region is particularly injurious. Equally, it does not appear that there is a substantial decrease in injury risk towards the extremity of the bumper (based on the division into five portions). Using the more detailed breakdown of the vehicle front from the GIDAS data, into ten parts, there is some suggestion that fewer AIS 2 injuries are caused by the outer 10 percent of the vehicle front either side, although the numbers are small for all regions.

The datasets were also examined for any variables that may cause bias in the distribution of contact position along the vehicle front. This is potentially important if, for instance, a group of casualties was more likely to be hit by the extremities of the vehicle and that group was more or less susceptible to injury than the rest of the pedestrian population. OTS and GIDAS provide information on the age, sex and movement of the pedestrian, the vehicle registration year and the speed of the collision, which were examined for bias (data not published here).

The age of the pedestrian and the vehicle appears to have no influence on the contact point distribution. However, both datasets show that males are more likely to be impacted by vehicles than females and that the distribution of contact points is different for males and females.

- It could be important for investigating injury risk across the bumper width if certain regions are associated with more males or females than another. In general terms, female leg bones tend to be narrower and have thinner cortical walls than males (e.g. [5]). Therefore one could speculate that female pedestrians may be more susceptible to some types of leg injury than male pedestrians.

- Whilst the distribution of males and female contact points was different, no obvious dominating trends were evident which would suggest one part of the vehicle front should be designed with a specific attention to protecting female pedestrians more than any other part.

Further study

One of the limitations of this work relates to the relative injurious nature of cars that have a pronounced tapered or angular bumper design and vehicles (perhaps older models) without those design features. This additional investigation was not carried out within this analysis because the case numbers from the OTS study would not allow such detailed investigation. In principle there may be enough cases in the GIDAS data and therefore it would be useful to investigate the differences in injury risk between these types of vehicles. However, care should be taken when defining this future study for the following reasons:

- There has been a trend for newer vehicle designs to have smaller bumper test areas. However, there are examples of car designs in the modern vehicle fleet where the bumper corners are still wider apart than is normal for most high-selling models. Therefore, there may be other design reasons to explain such differences. The comparison between cars with angled or curved bumpers and those with larger test areas could be compromised by other vehicle design changes in those two groups.

- Case numbers are limited even in the GIDAS groups. Features of the crash conditions that will have to be taken into account when considering the injurious nature of vehicle designs are: the severity of the collision, the fragility of the pedestrian and the contact position on the vehicle. There were 242 leg injuries of all severities (133 to the lower leg and 66 to the knee), of which 80 were AIS 2 in the GIDAS sample. This number would allow statistical treatment of the crash conditions and then investigation of the relationship of vehicle age and vehicle design. However, there were only 51 lower leg injuries from contacts to the two outer segments of the vehicle front, which would preclude such an analysis. Therefore, it is still marginal as to whether meaningful results can be obtained from the investigation of whether front-end shape affects injury risk for pedestrian accidents.

CONCLUSIONS

The frequency of pedestrian contacts is skewed towards the nearside in both the UK and Germany (statistically significantly in the case of Germany). However, the distribution is approximately linear, so the risk of being struck across the bumper (i.e. by the centre or outer parts) is equal assuming vehicles are symmetrical.

The sample numbers were too small for statistical analysis of the relationship of bumper impact location to injury severity. However, observations of the GIDAS dataset show that lower leg injuries, and injuries in general, occurred at a greater frequency towards the nearside of the bumper suggesting the bumper is equally injurious across its full width. The OTS dataset is far smaller than its German counterpart so the trends shown in the data are not as reliable. The data show that injuries to regions of the lower limb occurred at all points along the bumper, while there is a peak in lower leg injuries occurring at the centre of the bumper. However, the overall number of injuries (of all severities) to the lower limb does follow the same tendency of occurring at the nearside of the bumper.

Such low sample numbers prevent robust conclusions being drawn; however, there is no evidence in either dataset to suggest that the edges of the bumper are less injurious than the centre.

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- Participants at the Bumper Test Area Task Force meetings, who provided information regarding performance of current vehicles and detailed discussion of the technical issues raised by this project.

- The United Kingdom Department for Transport for permitting the use of the OTS (On-The-Spot) accident study. The OTS data forms part of the Road Accident In Depth Studies database, further information can be found at: https://www.gov.uk/government/publications/road-accident-investigation-road-accident-in-depth-studies

- VUFO GmbH for contributing accident data from GIDAS (German In-Depth Accident Study) to the study. GIDAS is the largest in-depth accident study in Germany. The data collected in the GIDAS project is very extensive, and serves as a basis of knowledge for different groups of interest. Due to a well defined sampling plan, representativeness with respect to the federal statistics is also guaranteed. Since mid 1999, the GIDAS project has collected on-scene accident cases in the areas of Hanover and Dresden. GIDAS collects data from accidents of all kinds. Due to the on-scene investigation and the full reconstruction of each accident, it gives a comprehensive view on the individual accident sequences and the accident causation.
  The project is funded by the Federal Highway Research Institute (BASt) and the German Research Association for Automotive Technology (FAT), a department of the VDA (German Association of the Automotive Industry). Use of the data is restricted to the participants of the project. However, to allow interested parties the direct use of the GIDAS data, several models of participation exist. Further information can be found at http://www.gidas.org.

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Comparative study of VRU head impact locations

T Kiuchi*, N Lubbe**, D Otte***, Q Chen****

*Toyota Motor Corporation, Vehicle Engineering Development Div., 1200, Mishuku, Susono, Shizuoka 410-1193 Japan
**Toyota Motor Europe NV/SA , Technical Affairs Planning Dept., Hoge Wei 33, 1930 Zaventem, Belgium
***Hannover Medical School, Accident Research Unit, Carl-Neuberg-Strasse 1, D-30625 Hannover, Germany
****China Automotive Technology & Research Center, 118 Westem Rd., South 4th Ring Rd., Fengtai District, Beijing 100070, China

Abstract - This study aimed at comparing head Wrap Around Distance (WAD) of Vulnerable Road User (VRU) obtained from the German in-depth Accident Database (GIDAS), the China in-depth Accident Database (CIDAS) and the Japanese in-depth Accident Database (ITARDA micro).
Cumulative distribution of WAD of pedestrian and cyclist were obtained for each database (AIS2+) showing that WAD of cyclists were larger than the ones of pedestrians. Comparing three regions, the 50%tile WAD of GIDAS was larger than that of both Asian accident databases. Using linear regression that might predict WAD of pedestrians and cyclists from *Impact speed* and *VRU height*, WADs were calculated to be 206cm/219cm (Pedestrian/Cyclist) for GIDAS, 170cm/192cm for CIDAS and 211cm/235cm for ITARDA.
In addition, this study may be helpful for reconsideration of WAD measurement alignment between accident reconstruction and test procedures.

INTRODUCTION

Vulnerable Road User (VRU) injuries are a raising concern in the world. Protection against head injuries is offered by softening structures and/or adding protective devices to the areas that are likely to be struck during an impact. The protection offered by a vehicle is assessed in regulatory and consumer testing. Probable impact areas have been investigated using simulation models (e.g. Mottola et al., 2013) and accident data. GIDAS information for example have been used to investigate cyclist and pedestrian head Wrap Around Distance (WAD) information, but results have not been directly comparable to test procedures (see e.g. Zander et al., 2013). Information from accident data on WAD from other regions are sparse. This study aimed at establishing cyclist and pedestrian head WAD information that are directly comparable to test procedures. Furthermore, it was analyzed whether differences between pedestrians and cyclist for head impact locations exist and whether regional influences are observable.

METHODS

Kinematics in pedestrian and bicycle accidents and comparison of WAD type 1 and type 2

At first, it is necessary to explain the kinematics during a car to pedestrian and a car to bicycle accident. In the next step it is essential to define the different measurement of WAD type 1 and type 2. Therefore the different measurement types are explained with an example of a car to pedestrian accident. The pedestrian kinematics in a car to pedestrian accident is in general divided into four different phases

- **Contact phase**
  This phase begins with the first contact between car and pedestrian and ends in the situation when the pedestrian has approximately adopted the vehicle speed or if there is a separation between car and pedestrian. This phase can be subdivided into two phases:
  - First contact with leg and hip (1. Acceleration, Fig.1)
  - Scoop up, impact of torso and head (2. acceleration) and maybe the following transport range (Fig.2)
- **Transport phase**
  If the car is not decelerating after the collision, it is possible (dependent on car type and design) that the pedestrian is transported on the engine hood or the roof of the car until the car is decelerating or the pedestrian falls of the car because of gravitation (Fig.3).

・**Flight phase**

This phase begins with the separation of the pedestrian and ends with the impact of the pedestrian on or next to the driving lane. A vehicle contact of a single body part is also possible during flight.

・**Slip phase**

This phase begins with the impact on or next to the driving lane and ends with the final position of the pedestrian.

In this study only the contact phase of the pedestrian until the head impact was important for measuring the wrap around distance. The different measuring methods of WAD type 1 and type 2 are explained in the next step.

Figure 1. Kinematics of pedestrian; Contact phase (First contact)

Figure 2. Kinematics of pedestrian; Contact phase (Scoop up)

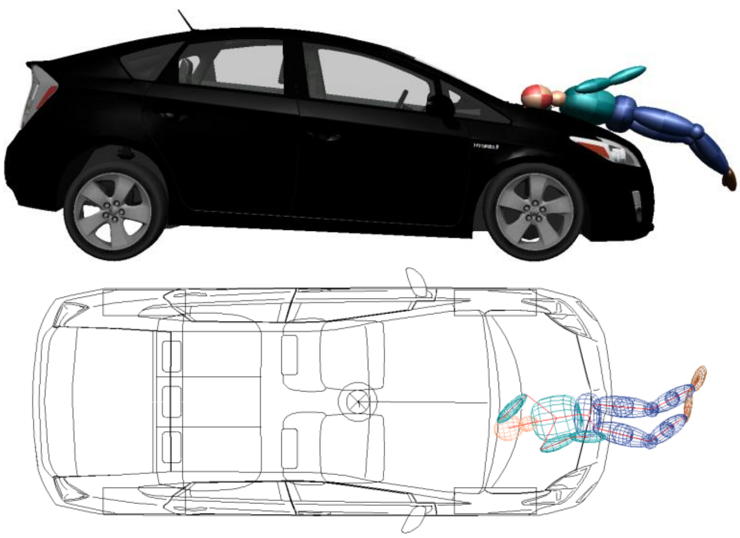

Figure 3. Kinematics of pedestrian; Transport phase

We suppose that the first impact of the right leg against the car front bumper has left a trace on the front bumper (scratch, dent) and the head impact has caused a dent in the engine hood. This traces are marked in the 3d-view of the car (Fig.4).

The distance in y-direction (lateral axis of the car) of the two dents is called **offset of the dents**. The measuring is always done from the middle of the dents or traces. In a perpendicular accident, the offset of the dents is only dependent on the movement speed of the pedestrian not on the speed of the car.
The distance in x-direction (longitudinal axis of the car) from the front of the car to the middle of the head impact dent is called **throw up distance**. The throw up distance depends on the movement speed of the car, the design of the cars front, body size and body weight of the pedestrian.

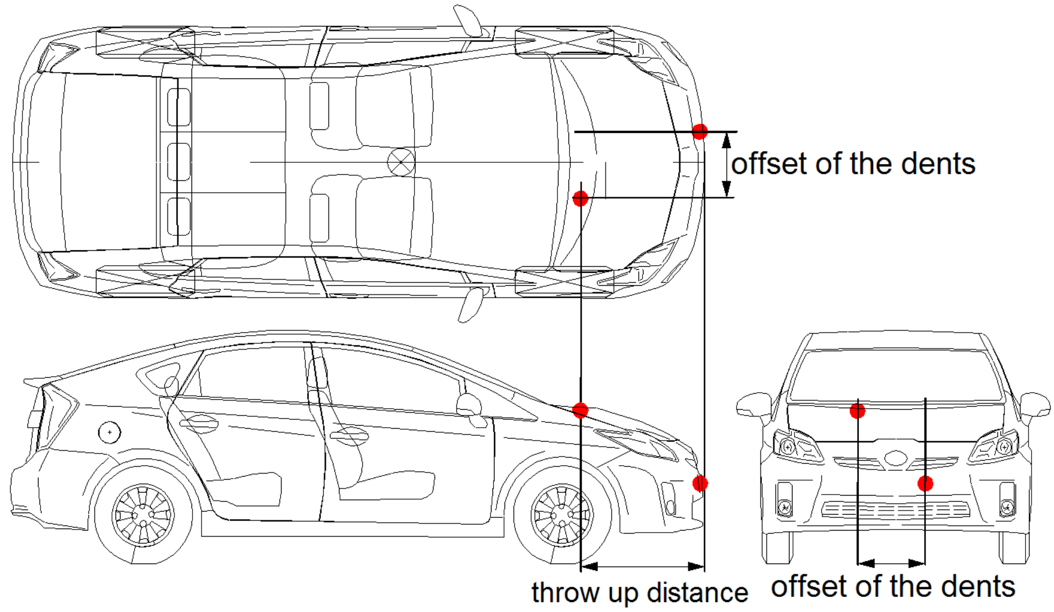

Figure 4. "offset of the dents" and "throw up distance"

The measuring of WAD is done with a measuring tape orthogonal under the first contact point of the vehicle front to the middle of the head impact point. The measuring of the WAD type 1 is done only in x-direction, thus along the lateral axis of the car (Fig.5) whereas the measuring of WAD type 2 is done in x-direction and in y-direction (Fig.6).

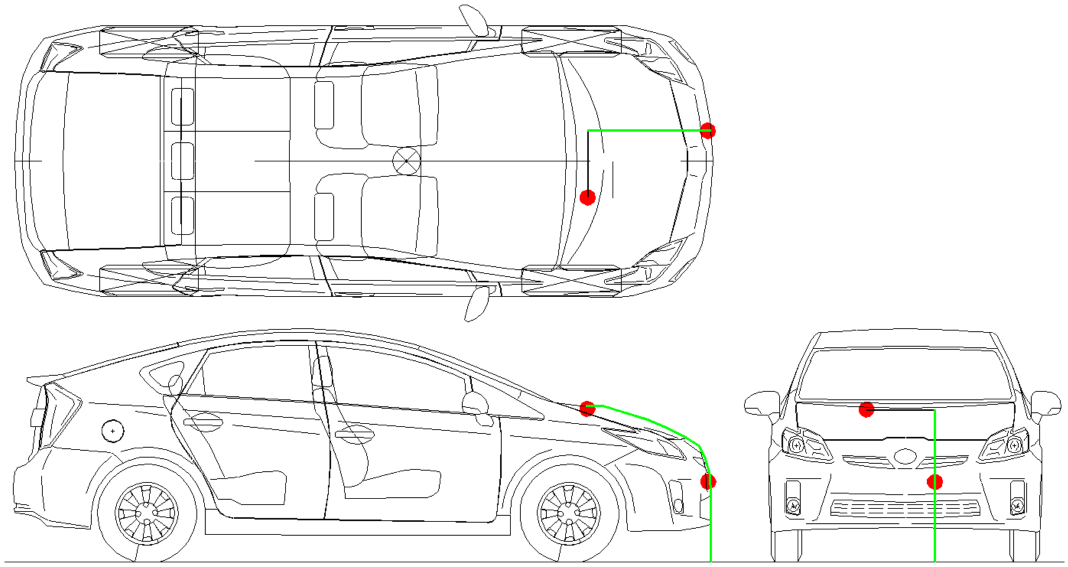

Figure 5. Measuring of WAD type 1

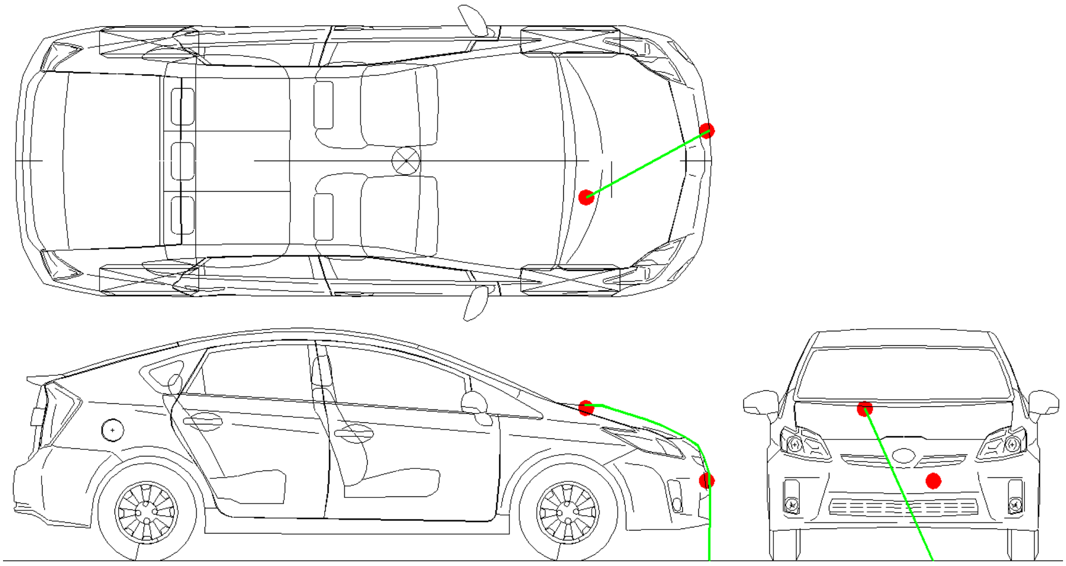

Figure 6. Measuring of WAD type 2

If there is no offset of the first contact at the front of the car and the head impact, the measurements of WAD type 1 and type 2 will show no difference. If there is an offset of the first contact at the front of the car and the head impact, the measurements of WAD type 1 and type 2 will show different results. Measuring with WAD type 2 will show larger wrap around distances than measuring with WAD type 1, because in the WAD type 2 a part of the offset of the first contact at the front of the car and the head impact is included.

Dependency of WAD on different parameters

As representative in-depth-accident study, GIDAS was used for finding frequencies of vehicle involvement. Accidents of the years 1999 to 2013 were analysed with focus on WAD.
GIDAS, CIDAS and ITARDA (micro) accident databases are used to extract head WAD for pedestrian and cyclists. For GIDAS, a case-by-case analysis was conducted to ensure the WAD information is directly comparable to test procedures, i.e. measured along the vehicle's longitudinal axis (type 1). For CIDAS and ITARDA (micro), WAD information is always measured along the vehicle's longitudinal axis (type 1), thus case-by-case analysis was not required.
Head impact WADs were plotted as empirical cumulative distributions with 95% confidence intervals using MATLAB R2013a. Differences between pedestrians and cyclists on the one hand and between the countries on the other hand were given. For each country, multivariate linear regressions were defined to explain WAD as an outcome of pedestrian height and vehicle speed.

RESULTS

Cumulative distributions of WAD for each database atAIS2+ injury level are shown in Fig.7, 8 and 9, respectively. In each country, WAD of cyclists was larger than that of pedestrians. Among the three accident regions, the 50 percentile WAD of GIDAS was largest.

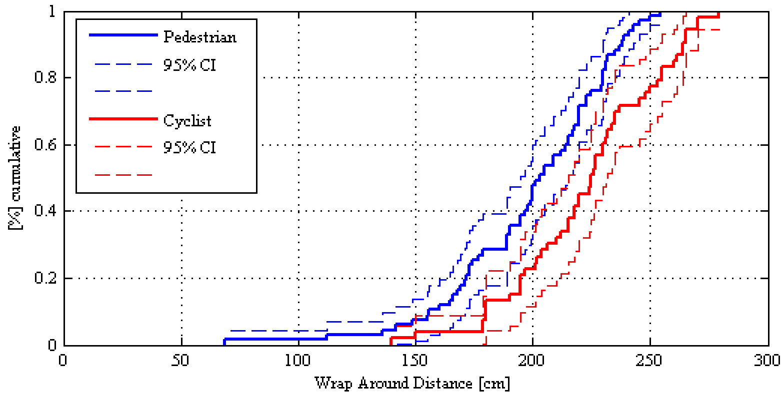

Figure 7. Cumulative distribution of Wrap Around Distance from GIDAS (AIS2+)

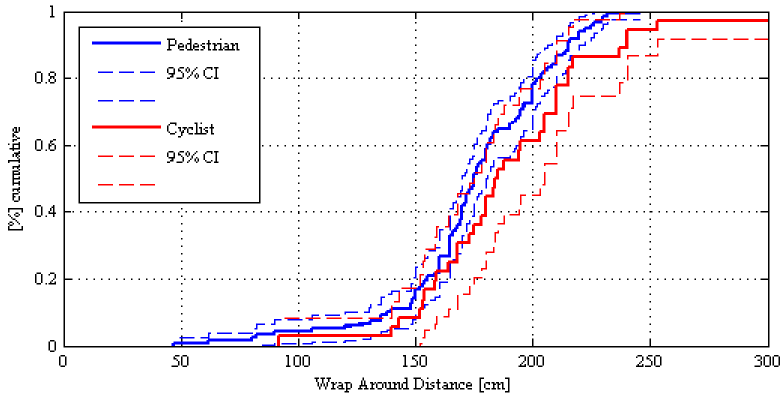

Figure 8. Cumulative distribution of Wrap Around Distance from CIDAS (AIS2+)

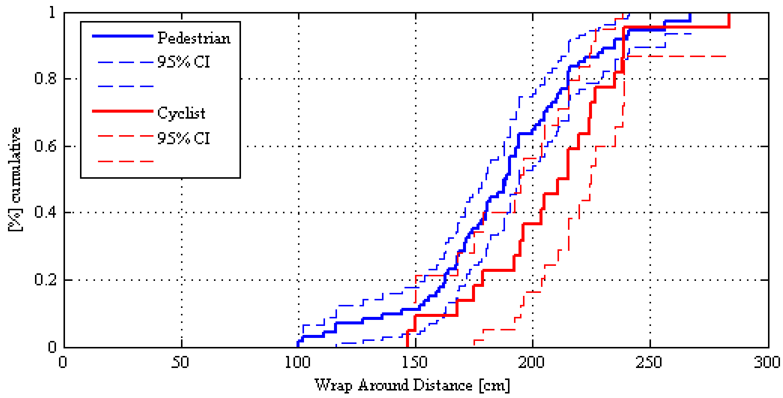

Figure 9. Cumulative distribution of Wrap Around Distance from ITARDA (AIS2+)

Linear regressions predicting WAD (cm)based on VRU height (cm) are shown in Fig.10, 11 and 12, respectively. Mean VRU heights and full model specifications of the three accident regions are given in table 1. Sample size (n), R^2 values and p-values for each predictor are given to indicate overall model fit. In Japan, the smallest mean VRU heights were observed.

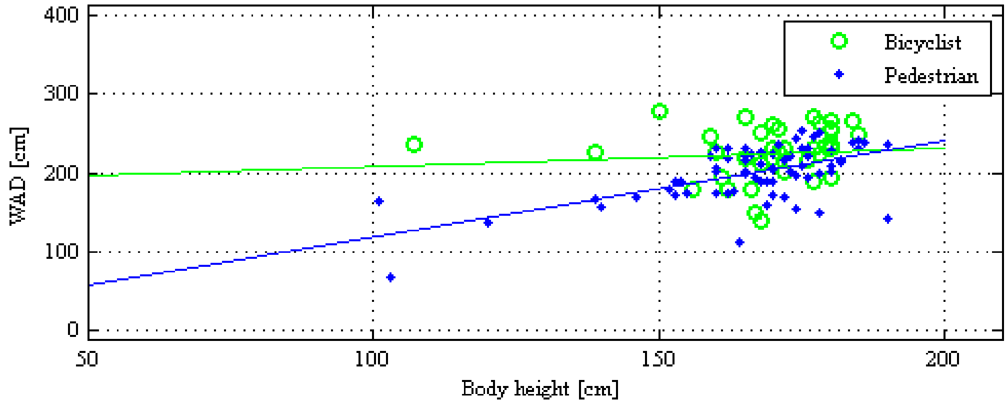

Figure 10. Linear regression WAD=f(VRU height) for GIDAS (AIS2+)

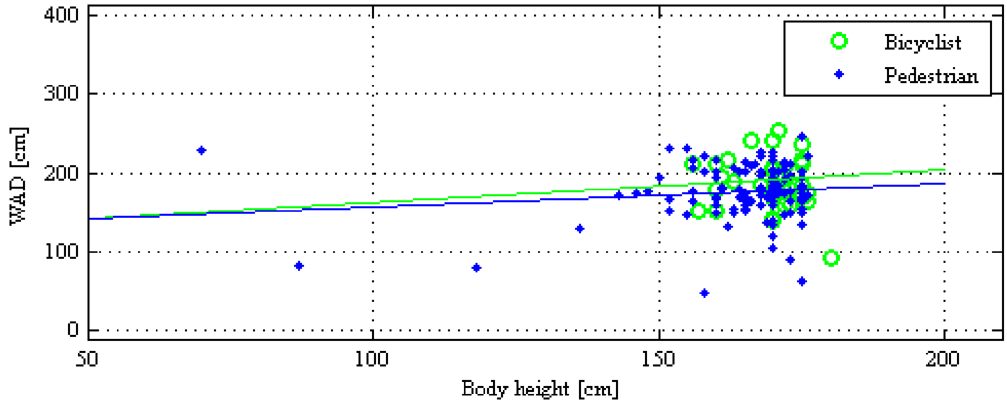

Figure 11. Linear regression WAD=f(VRU height) for CIDAS (AIS2+)

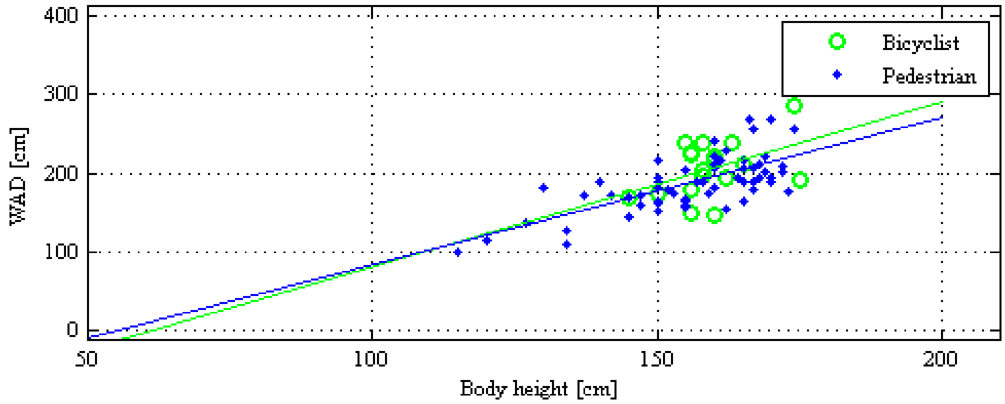

Figure 12. Linear regression WAD=f(VRU height) for ITARDA (AIS2+)

Table 1: VRU height description and model specification for linear regression WAD=f(VRU height)

		VRU height		Intercept			VRU height				
		mean	SD	value	SE	p	value	SE	p	n	R^2
GIDAS	Ped	166	16.7	-2.53	34.5	0.94	1.21	0.21	<0.01	67	0.35
	Cyc	169	13.2	185.8	66.8	<0.01	0.23	0.39	0.56	39	<0.01
CIDAS	Ped	163	17.1	125.5	36.1	<0.01	0.30	0.22	0.17	118	0.02
	Cyc	167	14.4	120.6	190	0.53	0.41	1.12	0.72	36	<0.01
ITARDA	Ped	156	13.3	-102.3	38.7	0.01	1.86	0.25	<0.01	60	0.49
	Cyc	161	8.0	-127.4	174	0.47	2.09	1.09	0.07	18	0.19

Linear regressions predicting WAD (cm) based on impact speed (km/h) are shown in Fig.13, 14 and 15. Mean impact speeds and full model specifications of three regions are given in table 2

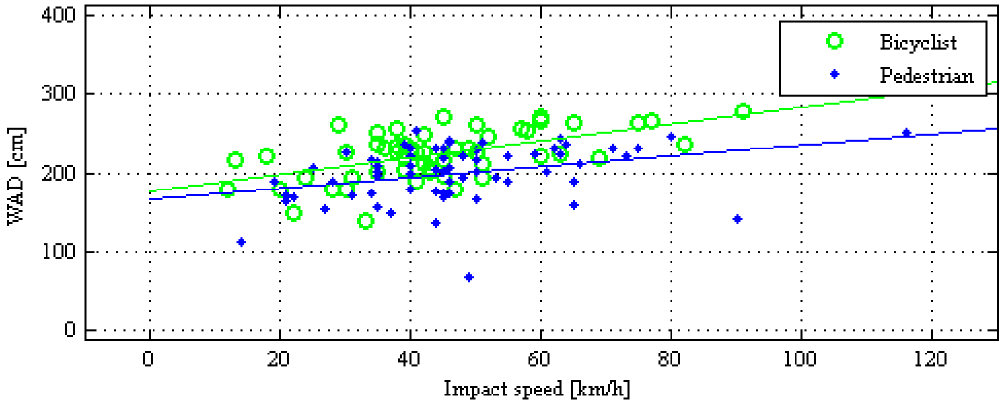

Figure 13. Linear regression WAD=f(impact speed) for GIDAS (AIS2+)

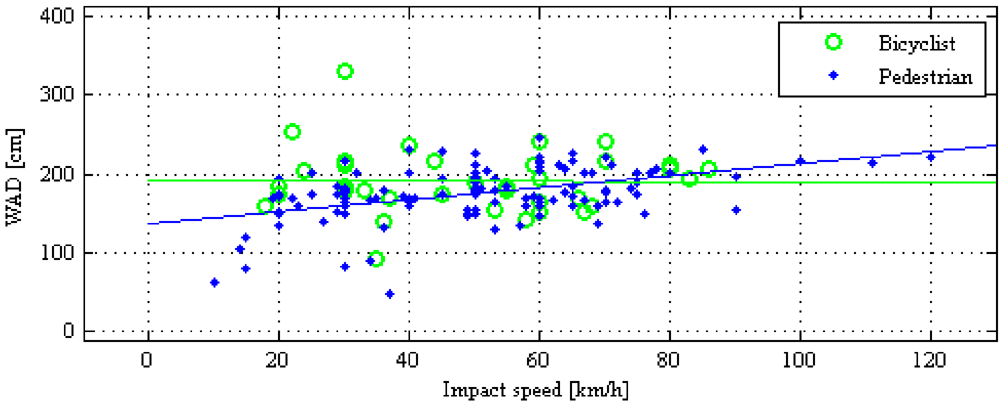

Figure 14. Linear regression WAD=f(impact speed) for CIDAS (AIS2+)

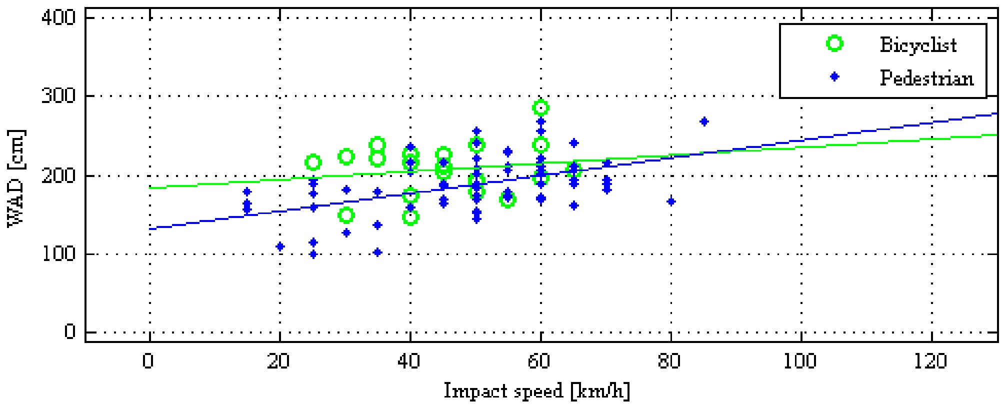

Figure 15. Linear regression WAD=f(impact speed) for ITARDA (AIS2+)

Table 2: Impact speed description and model specification for linear regression WAD=f(speed)

		Impact speed		Intercept			Impact speed				
		mean	SD	value	SE	p	value	SE	p	n	R^2
GIDAS	Ped	47	17.4	167.7	11.7	<0.01	0.67	0.23	<0.01	66	0.11
	Cyc	49	17.5	175.9	10.2	<0.01	1.07	0.22	<0.01	53	0.32
CIDAS	Ped	44	23.8	137.3	7.3	<0.01	0.75	0.13	<0.01	119	0.21
	Cyc	38	19.9	192	18.5	<0.01	-0.03	0.35	0.93	36	<0.01
ITARDA	Ped	49	16.0	132.4	12.1	<0.01	1.12	0.24	<0.01	72	0.24
	Cyc	44	12.4	184.1	30.9	<0.01	0.51	0.66	0.45	21	0.03

Table 3 displays model specifications for linear regression that predicts WAD of pedestrian and cyclists (in cm) using impact speed (km/h) and VRU height (cm) simultaneously.

Table 3: Model specification for linear regression WAD=f(impact speed,VRU height)

		Intercept			Impact speed			VRU height				
		value	SE	p	value	SE	p	value	SE	p	n	R^2
GIDAS	Ped	-1.7	34	0.96	0.35	0.21	0.09	1.11	0.21	<0.01	66	0.38
	Cyc	172	54	<0.01	1.14	0.25	<0.01	0.01	0.32	0.97	39	0.37
CIDAS	Ped	105	32	<0.01	0.74	0.13	<0.01	0.20	0.20	0.32	118	0.22
	Cyc	114	220	0.61	0.03	0.39	0.95	0.44	1.25	0.36	36	<0.01
ITARDA	Ped	-93	36	0.01	0.68	0.20	<0.01	1.58	0.24	<0.01	58	0.59
	Cyc	-135	178	0.46	0.49	0.74	0.52	2.0	1.12	0.09	18	0.21

Using these linear regressions, VRU WADs (in cm) are predicted under the condition that a VRU height is 175 cm and an Impact speed is 40 km/h. Table 4 gives predicted WADs.

Table 4: Predicted WAD for a VRU of 175 cm and an impact speed of 40 km/h

	GIDAS	**CIDAS**	**ITARDA**
Pedestrian	206	170	211
Cyclist	219	192	235

ITARDA has the largest predicted WAD for both Pedestrian and Cyclist at these conditions, but differences to GIDAS are small with less than 20 cm. CIDAS predicted WAD is by far the shortest.

DISCUSSION

The results of this study can guide the definition of a probable head impact area and in turn aid the development of protective devices and test procedures.

The results are based on retrospective accident data, which under samples non-injury cases and might be prone to measurement error. Partly small sample sizes in the linear regression models and less-than-ideal model fit needs to be taken into consideration when interpreting results. Thus, the findings of this study should be supplemented using simulation methods. Edwards et al. (2014) give a simulation based prediction of pedestrian head WAD in the form WAD = -2227 + 335 * log(impact speed) + 1.8 * Pedestrian height. WAD and height are measured in mm, impact speed in km/h.

For the impact condition in table 4, 216cm WAD are predicted, which is 5 to 10 cm larger than results from ITARDS and GIDAS, respectively.

Fredriksson and Rosén (2012) used GIDAS AIS3+ data to calculate an equation WAD = -28 + 0.49 * Impact speed + 1.2 * Pedestrian height, where WAD and height are given in cm, impact speed in km/h. For the impact condition in table 4, 201 cm WAD is predicted, which is comparable to our study.

CONCLUSION

- Head impact WAD for pedestrians and cyclists in Germany, China and Japan are established in a manner that is directly comparable to test procedures. Influential factors VRU height and impact speed that determine WAD are quantified.

- For each of the three countries, WAD is predicted using VRU height and impact speed. These predictions might indicate areas relevant for VRU impact protection.

- Lastly, this study may be helpful for reconsideration of WAD alignment between accident reconstruction and test procedures.

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Injury severity resulting from accidents with reversing cars

Decker, Sebastian[1], M.D.; Otte, Dietmar[2]; Müller, Christian W.[1], M.D.; Omar, Mohammed[1], M.D.; Krettek, Christian[1], M.D.; Brand, Stephan[1] M.D

[1] Trauma Department, Hannover Medical School, Germany
[2] Accident Research Unit, Hannover Medical School, Germany

Author for Correspondence: Sebastian Decker. Address: Trauma Department, Hannover Medical School, Carl-Neuberg-Str. 1, 30625 Hannover, Germany. Tel.: +49-511-5322026 Fax: +49-511-5325877. E-mail address: Decker.Sebastian@mh-hannover.de.

Background: Injury severity of e.g. pedestrians or bikers after crashes with cars that are reversing is almost unknown. However, crash victims of these injuries can be seen frequently in emergency departments and account for a large amount of patients every year. The objective of this study is to analyze injury severity of patients that were crashed into by reversing cars.

Methods: Our local accident research unit prospectively documented 43000 road traffic accidents including 234 crashes involving reversing cars. Injury severity including the abbreviated injury scale (AIS) and the maximum abbreviated injury scale (MAIS) was analyzed as well as the location of the accident.

Results: 234 accidents were included into this study. Pedestrians were injured in 141 crashes followed by 70 accidents involving bikers. The mean age of all crash victims was 57 ± 23 years. Most injuries took place on straight stretches (n = 81) as well as parking areas (n = 59), entries (n = 36) or crossroads (n = 24). Accident locations are presented in figure 1. The AIS of the lower extremities was highest followed by the upper extremities, 0.8 ± 0.7 and 0.5 ± 0.6 respectively. The AIS of the neck was lowest (0.1). The mean MAIS was 1.3 ± 0.6 (Figure 2).

Conclusions: The lower extremities show the highest risk to become injured during accidents with reversing cars. However, the risk of severe injuries is likely low.

Figure 1: Accident location of different traffic participants in crashes with reversing cars.

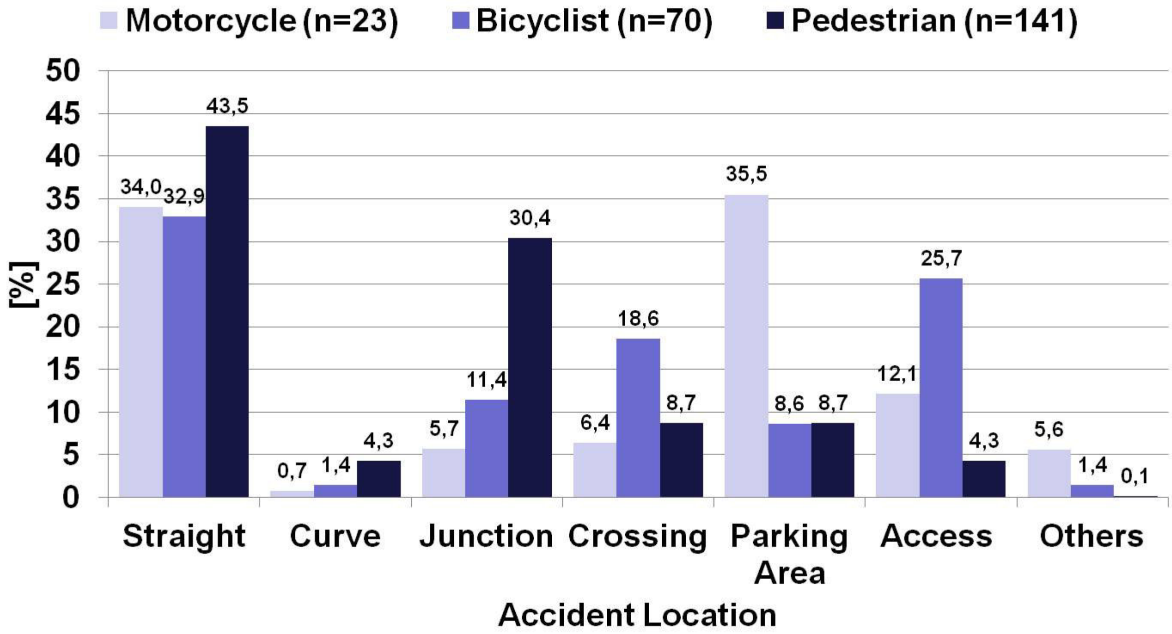
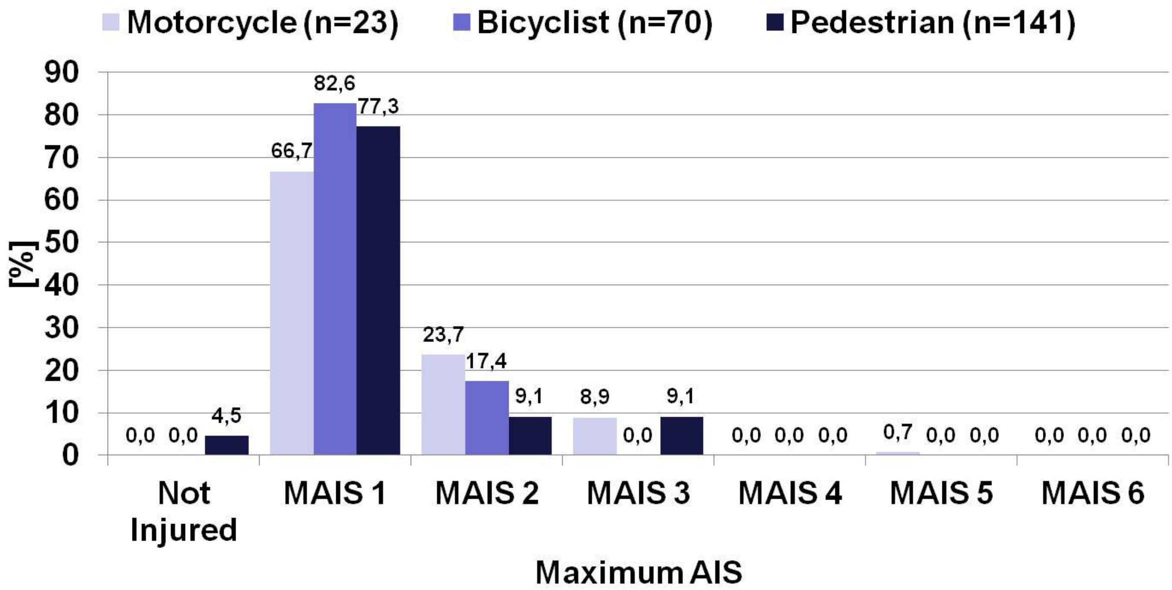


Figure 2: MAIS of different traffic participants in crashes with reversing cars.



Blunt aortic injuries caused by high velocity traffic accidents –Open repair vs. TEVAR in multiple injured patients
-Observations from a Level-1 trauma centre –

Stephan Brand[1], MD, Ingo Breitenbach[2], MD, Philipp Bolzen[3], MD, Maximilian Petri[1], Max Ettinger[5], Carl Haasper[1], MD, PhD, Christian Müller[1], MD, Christian Krettek[1], MD, PhD, FRACS, Omke Teebken[4], MD, PhD, FEBVS

[1] Trauma Department Hannover Medical School (MHH), Germany
[2] Department of Cardiothoracic and Vascular Surgery, Public Hospital Braunschweig, Germany
[3] Department of Diagnostic Radiology, Hannover Medical School
[4] Department of Cardiothoracic, Transplantation and Vascular Surgery, Hannover Medical School
[5] Department of Orthopedic Surgery, Hannover Medical School

Introduction

Ruptures and dissections of the thoracic and abdominal aortic vessel caused by traffic accidents are rare but potentially life-threatening injuries (*1-3*). Injuries can occur by blunt trauma via seat belt or dashboard injury, penetrating injuries are more often associated with gunshot or stepping wounds (*4-6*).

Over the years the treatment algorithm regarding traumatic aortic injuries has changed:

Therapy of blunt traumatic aortic injury mainly depends on the severity of the injury and the anatomical position (*7-9*).

Only intimal tear injuries are a domain of non-operative treatment, all other types of lesions should be repaired urgently. With the improvements in techniques and diagnostics the treatment algorithm has changed to the frequent use of minimally invasive stents rather than open repair where applicable. The goal of our study was to evaluate the overall mortality, morbidity, neurological disorders, and differences in operative procedures of open repair and stenting.

Material and Methods

From 1977 to 2012 all severely injured patients transferred to our level-1 trauma centre with air rescue unit were screened for blunt traumatic aortic injuries. Severely injured was determined with an ISS of 16 or higher (*10*). Two groups were formed depending on performed treatment of traumatic aortic injury. Group one was treated with open repair; group two was treated with stentgrafts. Overall-mortality, 30-day mortality, ISS scores and demographic data of both groups were compared.

All patients were seen immediately by trauma surgeons in the emergency unit and treatment algorithm was depending on overall medical situation of the patient and extends of accessory injuries (*11*).

Ultrasound of the abdominal cavity as well as of the pericardium was performed within minutes after arrival at the hospital. X-rays were taken from chest, pelvic ring and cervical spine as part of the ATLS®-based trauma algorithm (*12*)(ATLS: Advanced Trauma Life Support). Blood samples were taken and the patient was stabilized with arterial and venous catheters where possible.

Patients were then transferred to the CT-scan for whole body trauma scan, patients before 1987 were diagnosed using digital subtraction angiography (DSA).

Diagnosis of blunt aortic injury was done via multiple-slice CT scan (since 2005 64 slices CT, Image 1).

Besides this, the patient monitoring includes demographic data, collision circumstances, injury pattern, Abbreviated Injury Scale (AIS), Maximum AIS, Injury Severity Score (ISS), incidence of serious or severe multiple injuries.

Decreases in 30-day mortality, in postoperative ICU stay and in transfusion of packed red cell units were expected.

Results

From 1977 to 2012 a total of 45 blunt aortic injuries caused by high velocity traffic accidents transferred to our hospital were observed. All patients suffered blunt trauma to chest and abdominal wall, and all were involved in high-energy traffic accidents.

Those who survived the immediate impact and resuscitation sustained multiple injuries with an average ISS of 41.8 (range 29-68). Some 25 Patients underwent open repair of thoracic aortic injuries between 1977 and 2005 (3 women; 22 men; mean age 27, range 18-69).

These patients were involved in traffic accidents as car driver and motorcycle drivers. The mean ISS in this group was 41.25 (range 29-68).

The second group consisted of 20 patients undergoing emergency stenting of intrathoracic aortic injuries between 2005 and 2012 (18 men; 2 woman; mean age 41.3, range 17-78); the mean ISS was 42.5 (range 29-48). Patients were involved in traffic accidents as car drivers, motorcycle riders and pedestrians.

Surgery was performed on the admission day in both groups and all cases (Image 1).

All patients were transferred to aortic repair within hours after hospital transfer.

In group one open repair via left lateral thoracotomy was performed using gelatin coated woven Dacron tube grafts. For TEVAR thoracic stentgrafts were used and implanted via femoral artery (Medtronic Vascular, Santa Rosa, CA, USA; W.L. Gore & Associates, Flagstaff, AZ, USA, Image 2).

Overall-mortality in both groups was 8/45 (%) and 30-day mortality was 7/45 (%).

Mortality of those undergoing open repair of aortic injury was 6/25 (24%), 30-day mortality 20% (5/25). The average time for open surgery was 151 min; the mean time for stenting was 67 min (p=0.001). Postoperative stay on the intensive care unit was between one and 59 days (mean 17) in group one and between four and 50 days in group two (mean 29)(p=0.03). Patients undergoing open repair required transfusion of 6.0 units of packed red cells in median; patients undergoing stenting required a median of 2.0 units of packed red cells (p<0.001).

With those undergoing immediate minimal invasive stenting 30-day mortality was 10% (2/20). The 30-day mortality decreased significantly (p=0.013, Mann-Whitney-test).

Neurological deficits were observed with three patients in the open repair group with persistent paraplegia and unilateral vocal cord paralysis in two cases. In the stent group one persistent paraplegia was observed. All but one stent were implanted via femoral artery, in one case a retrograde stenting of the thoracic aorta was performed with open heart massage. This patient died at day six due to multi-organ failure. The left subclavian artery was cross-stent in eight patients, none of these presented with additional neurological deficits.

In the open repair group 22 patients were treated emergently within six hours of hospital admission (88%); in the stent group 18 patients were treated within six hours of admission (90%).

The ISS scores were not significantly higher in the stent group compared to the open repair group (ISS stent 42.5 vs. ISS open repair 41.25; p= n.s.).

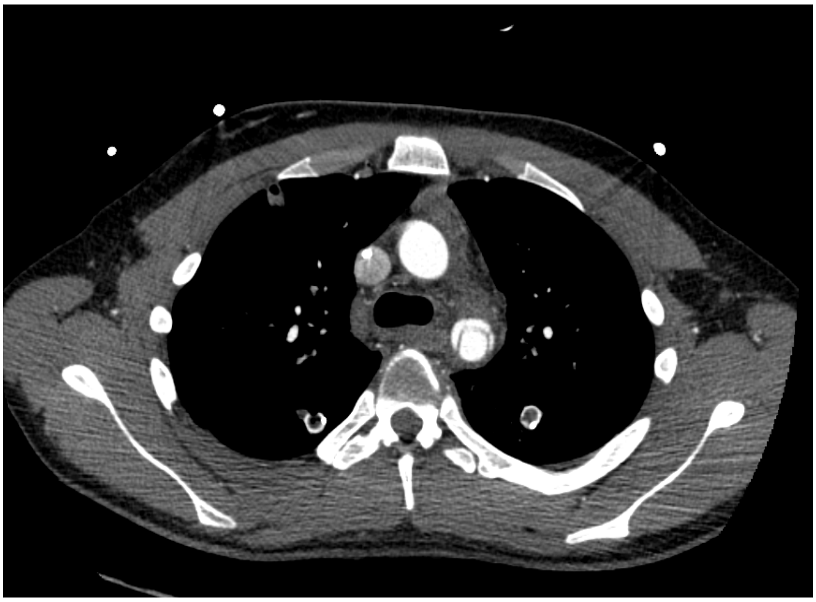


Image 1: Traumatic dissection of the thoracic aorta distally to the left subclavian artery

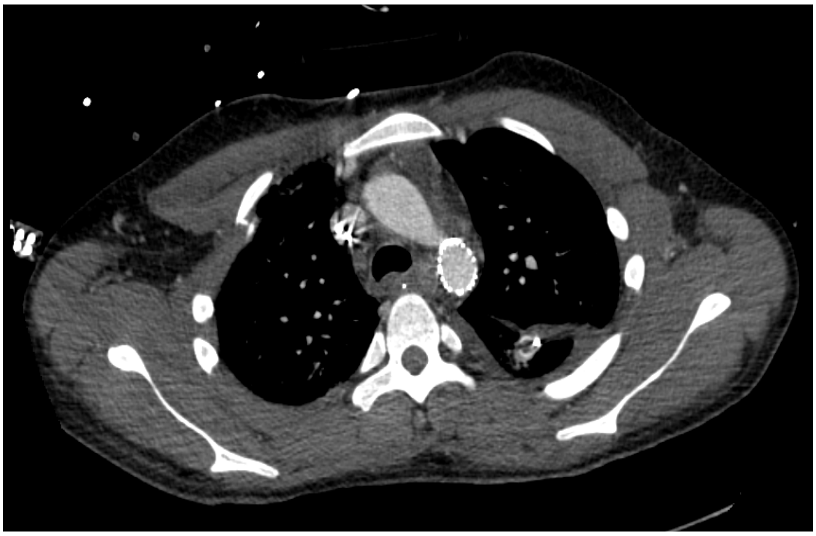


Image 2: Successfully performed minimally invasive stenting of the lesion above

Discussion

There was an increase in patients diagnosed with traumatic aortic injury per year observed since 1995. This could be due to an increase in the quality of prehospital trauma car as well as improvements in diagnostic tools.

The most important finding of our study was a decrease of in-hospital mortality since changes in surgical treatment. From 1977 to 2004 the treatment algorithm consisted of open repair when a traumatic thoracic aortic injury was diagnosed. With the improvement of diagnostic tools (since 2005 64 slices ct scan) and improvements with the use of minimally invasive stentgrafts the in-hospital mortality decreased significantly (p=0.013 Mann-Whitney-test). Furthermore, decrease in transfusion of packed red cell units was significant and time required for surgery was significantly shorter with stenting.
Surprisingly, in contrast to our expectations a significant increase in postoperative ICU stay in the stent group was observed. This could be due to changes in treatment algorithms from early total care orthopedics to damage control surgery (*11, 13-15*) as well as changes in treatment algorithms of severely injured patients, e.g. continuous lateral rotational kinetic therapy in patients with major thoracic trauma and lung contusion.
Previous investigations showed similar results with a significant lower mortality rate with patients undergoing endovascular repair (*6, 16-19*). Complications described were type-1endoleaks (*17*) and partially recovered paraplegia (*6*).

Conclusion

With the change and improve in diagnostic tools and surgical approach mortality and morbidity of blunt aortic injuries were significantly reduced. Still an immediate life-threatening injury early diagnosis via multiple-slice ct scans and surgical repair with minimally invasive stents showed excellent short-time results for selected patients.

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A methodology to evaluate injury risk and accident conditions from injuries in vehicle-to-pedestrian accidents

Paulo Francisco*, Ana Ferreira*, Ricardo Portal*, João M. P. Dias*

* LAETA, IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal
E-mail: paulo.francisco@tecnico.ulisboa.pt, jdias@dem.ist.utl.pt

Abstract - Pedestrians represent about 20% of the overall fatalities in Europe's road traffic accidents. In this paper a methodology is proposed to understand why the numbers are so high, especially in the south of Europe and particularly in Portugal, . First a detailed statistical analysis using Ordinal Logistic Regression model (OLR) was applied to the gathered data from all Portuguese accidents with victims in the period 2010-2012. In a second stage accident reconstruction computational techniques using pedestrian biomechanical models are used to evaluate the accident conditions that lead to the injuries, such as the speed and the impact location. For biomechanical injury criterions, the AIS (Abbreviated Injury Scale), the HIC (Head Injury Criterion) and other injury criterions based on the resulting accelerations in the pedestrian's body are used.

The statistical model reported that there were several predictors that significantly influenced the pedestrian injury severity in the event of a road accident, such as Pedestrian's age, Pedestrian's gender, Vehicle Design/Category or Driver's gender. The use of injury scales and biomechanical criterions in in-depth investigation of road accidents, such as AIS, can significantly improve the quality of the reconstruction process.

NOTATION

HIC	Head Injury Criterion
ANSR	Portuguese National Road Safety Authority
AIS	Abbreviated Injury Scale
a	Acceleration
EES	Energy Equivalent Speed
m	Mass
t	Time
v	Velocity
OR	Odds Ratio

INTRODUCTION

The 2013 global status report on road safety conducted by the World Health Organization [1] states that injuries resulting from road traffic accidents are a public health problem and an impediment to development, being expected, if immediate measures are not implemented, that road accidents will become the 5th leading cause of death in the world by 2030. The Southern European countries have specific accident patterns and Portugal is one of them. Despite the recent reduction in road accident numbers reported in Portugal, it has not been reflected so distinctly among pedestrians, which still present concerning numbers of road accidents and in terms of accidents severity. Pedestrian fatalities are a social health issue in Portugal. For every 100 accidents of the same type, cars generate 1.5 fatalities whereas pedestrian run-overs generate 3.4.

Figure 1 shows the evolution in the number of pedestrian fatalities in the European Union with 15 Member States (excluding Luxembourg because of its small numbers) up to the available 2012 data according to the latest CARE database statistics [2]. From this perspective it is clear that even having a continuous improvement since 2000, Portugal still constitutes one of the worst cases in terms of pedestrian accidents in the most recent years, lagging behind the European average and around the same level as or below larger countries.

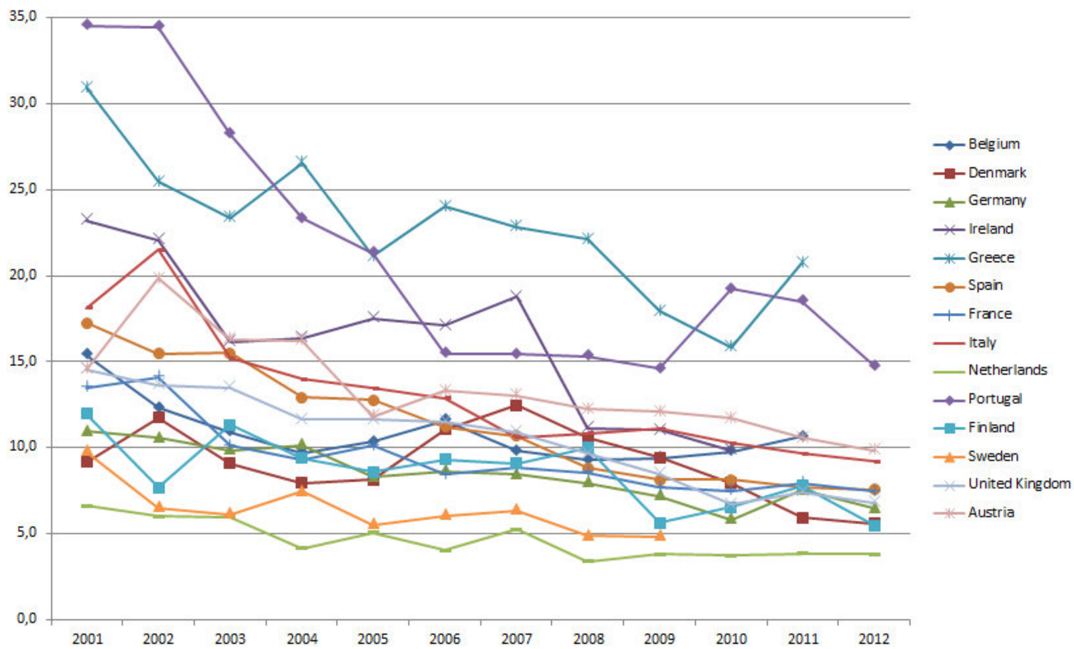

Figure 1. Pedestrian fatalities per million inhabitants in the EU15.

In 2012 alone, in Portugal's mainland, 38823 casualties in road accidents occurred, resulting 718 deaths, from which 22% were pedestrians [3]. It follows that pedestrian accident severity in Portugal is a real problem that demands the development and implementation of specific road safety measures. Through the statistical analysis of road accidents one can determine patterns and identify the determinant factors in the occurrence and severity of accidents, and in this particular case, of pedestrian accidents. The in-depth study of these specific accidents, resorting to scientific methods and namely, the use of computational models, allows the increase of knowledge in this particular field in order to evaluate tendencies, isolate problems and areas where taking actions is a priority and supports the development of effective countermeasures to improve pedestrian safety.

METHODS

This work uses the 2010, 2011 and 2012 accident databases of Portuguese National Road Safety Authority (ANSR) [4]. Each of them encompasses detailed information on every accident with victims occurred in the 2010-2012 three year period, such as casualties, injury severity, crash location, main cause of collision, alcohol tests, among others. Concerning pedestrians, the database stores information on 16305 run-overs.

During the database preparation, a critical assessment of the validity and consistency of each entry was performed. In some run-overs, the pedestrian was hit by more than one vehicle. In such cases, only the primary vehicle's information was considered. On the other hand, the Portuguese National Road Safety Authority stores their accident data in different tables, i.e., there is a table for the accidents themselves, a table for drivers, a table for passengers and a table for pedestrians. This method poses some problems, as the only common column is the accident ID. In such a way, using the raw database it is impossible, for instance, in the driver's table to determine the injuries caused to the pedestrians or in the pedestrian's table to determine which type of vehicle hit the pedestrian. To overcome this, a Matlab routine was developed to connect all the information in a new table to be used for the statistical analysis. In this process, the pedestrian run-overs that did not possess driver's information were eliminated, as well as the remainder of the entries with missing values on relevant variables, namely, 3400 entries. The final sample was comprised of 12905 pedestrian victims, 11502 of which sustained slight injuries, 964 severe injuries and 434 fatalities. Levels of injury severity resulting from a crash are included in the ANSR database [4] thereby enabling the construction of a categorical variable that captures different ranks of severity following a similar strategy as Albalate and Fernández-Villadangos [5]. Thus, the dependent variable contains 3 increasing degrees of severity according to police reports following the crash: slight, severe, and fatal. The ordinal regression was then applied using a number of potential determinants as explanatory variables of injury severity to estimate the determinants of differences in the degree of accident severity. The theoretical background concerning regression models and in particular, ordinal regression models, is described more in detail in the literature [6, 7].

STATISTICAL ANALYSIS

The results are presented in terms of the odds ratio (OR) associated to each predictor category. If OR = 1, it indicates that there is no effects in the categories in analysis. If OR > 1 or OR < 1, it indicates an increase or a decrease in the likelihood [7]. For all these conclusions and analyses we also need to consider the statistical significance (p-value) of the results. A 95% confidence interval (CI) was used because a p-value of 5% is the convention for rejecting the null hypothesis in a significance test. This means that there is 95% likelihood for the fact that true OR value falls between the lower and upper portion of the 95% confidence interval.

The demographic results confirm what is commonly assumed. Table 1 shows that for pedestrians there is a decrease in injury severity the younger they are, when compared to the reference category. For the younger pedestrians considered, aged up to 14, the 95% confidence interval reports an OR between 0.750 and 0.516. Regarding vehicle drivers, the reference category is an age between 30 and 39 and only one category was found to be statistically significant, namely, category 4 (more than or equal to 70). The results indicate that there is a decrease in injury severity when the vehicle driver is an elderly person, with an OR of 0.725. Note that the entire 95% confidence interval reports a reduction in injury severity, with results between 0.557 and 0.943.

Table 1 - Estimates on the determinants of road accident severity for the Pedestrian's Age variable.

Variable	Description	OR	p-Value	95% Confidence Interval		N	Frequency
Pedestrian's Age	1. Less than or equal to 14	0.623	0.000	0.750	0.516	2113	16.4%
	2. 15 - 39	0.607	0.000	0.713	0.516	3092	24.0%
	3. 40 - 64	0.675	0.000	0.780	0.584	3801	29.5%
	4. More than or equal to 65 (reference)	--	--	--	--	3994	30.2%

Table 2 - Estimates on the determinants of road accident severity for the Driver's Age variable.

Variable	Description	OR	p-Value	95% Confidence Interval		N	Frequency
Driver's Age	1. 40 - 49	1.040	0.655	1.232	0.877	2649	20.5%
	2. 50 - 59	0.871	0.159	1.055	0.719	2028	15.7%
	3. 60 - 69	0.916	0.422	1.135	0.739	1433	11.1%
	4. More than or equal to 70	0.725	0.016	0.943	0.557	1066	8.3%
	5. Less than or equal to 19	0.954	0.806	1.392	0.653	363	2.8%
	6. 20 - 29	1.161	0.086	1.376	0.979	2415	18.7%
	7. 30 - 39 (reference)	--	--	--	--	2946	22.8%

Driver's gender, displayed on Table 2, also plays an important role in injury severity. If the vehicle driver is of the female gender, an OR of 0.829 reports a decrease in injury severity, which extends to the whole 95% confidence interval, with values lying between 0.721 and 0.952.

Table 3 - Estimates on the determinants of road accident severity for the Driver's Gender variable.

Variable	Description	OR	p-Value	95% Confidence Interval		N	Frequency
Driver's Gender	1. Feminine	0.829	0.008	0.952	0.721	3408	26.4%
	2. Masculine (reference)	--	--	--	--	9492	73.6%

Portugal's capital city is Lisbon. It is commonly assumed by the Portuguese that Lisbon has a great deal of Portugal's road accident victims. Where pedestrians are concerned, Lisbon has in fact the highest number of fatalities, the highest number of severe injured and the highest number of slightly injured. Lisbon also has the highest number of habitants. The geographic analysis presented in Table 4 concludes that, even though Lisbon leads the way in terms of global numbers, the pedestrian injury severity increases in every other District. Note that two of them, Coimbra and Oporto, are not statistically significant, on account of their higher than 0.05 p-value.

Table 4 - Estimates on the determinants of road accident severity for the District variable.

Variable	Description	OR	p-Value	95% Confidence Interval		N	Frequency
District	1. Aveiro	1.317	0.042	1.714	1.010	777	6.0%
	2. Beja	2.197	0.007	3.896	1.239	88	0.7%
	3. Braga	1.958	0.000	2.433	1.575	1057	8.2%
	4. Bragança	3.281	0.000	5.280	2.038	109	0.8%
	5. Castelo Branco	2.210	0.000	3.408	1.433	176	1.4%
	6. Coimbra	0.854	0.427	1.261	0.579	432	3.3%
	7. Évora	2.286	0.001	3.728	1.402	134	1.0%
	8. Faro	2.077	0.000	2.697	1.602	607	4.7%
	9. Guarda	2.168	0.002	3.532	1.331	121	0.9%
	10. Leiria	1.422	0.016	1.893	1.069	590	4.6%
	11. Viseu	1.571	0.006	2.173	1.137	411	3.2%
	12. Portalegre	2.452	0.001	4.216	1.426	96	0.7%
	13. Oporto	1.142	0.159	1.374	0.949	2647	20.5%
	14. Santarém	2.307	0.000	3.152	1.689	360	2.8%
	15. Setúbal	1.470	0.001	1.848	1.169	1081	8.4%
	16. Viana do Castelo	1.786	0.002	2.588	1.234	264	2.0%
	17. Vila Real	1.557	0.038	2.363	1.025	229	1.8%
	18. Lisbon (reference)	--	--	--	--	3721	28.8%

Regarding road grip conditions, the considered reference category was a clean and dry surface (see Table 5). The analysis determined that if the road surface is coated with ice, frost, snow, gravel or sand there is a massive increase in injury severity. In the ice frost or snow category, the 95% confidence intervals predicts an OR that can be as high as 18.247. Unfortunately, the wet surface category was not found to be statistically significant.

Table 5 - Estimates on the determinants of road accident severity for the Grip Conditions variable.

Variable	Description	OR	p-Value	95% Confidence Interval		N	Frequency
Grip Conditions	1. Wet	0.966	0.575	1.092	0.853	4897	38.0%
	2. With ice, frost or snow	4.371	0.043	18.247	1.048	7	0.1%
	3. With gravel or sand	3.364	0.004	7.706	1.470	26	0.2%
	4. Clean and dry (reference)	--	--	--	--	7970	61.8%

The analysis of lighting conditions presented on Table 6 determined that there is an increase in injury severity the worse they are, with both night categories presenting OR's greater than 1. Comparing categories 2 and 3, it can be concluded that the absence of illumination during nigh time is a critical factor for pedestrian injury severity.

Table 6 - Estimates on the determinants of road accident severity for the Luminosity variable.

Variable	Description	OR	p-Value	95% Confidence Interval		N	Frequency
Luminosity	1. Dawn or dusk	1.269	0.152	1.756	0.917	401	3.1%
	2. Night, with illumination	1.242	0.022	1.496	1.031	2810	21.8%
	3. Night, without illumination	2.024	0.000	2.633	1.556	491	3.8%
	4. Day (reference)	--	--	--	--	9198	71.3%

Vehicle type was also considered as a possible determinant of injury severity. Being a light vehicle the reference category, the results presented on Table 7 state that there is a decrease of injury severity when getting hit by a two-wheeled vehicle and an increase of injury severity when the pedestrian is hit by a heavy goods vehicle.

Table 7 - Estimates on the determinants of road accident severity for the Vehicle Category variable.

Variable	Description	OR	p-Value	95% Confidence Interval		N	Frequency
Vehicle Category	1. Heavy goods vehicle	2.366	0.000	2.980	1.878	516	4.0%
	2. Motorcycle/Moped	0.457	0.000	0.665	0.314	492	3.8%
	3. Other (agricultural or industrial vehicle, vehicle on rails)	2.002	0.013	3.456	1.161	81	0.6%
	4. Bicycle (with or without an engine)	0.440	0.044	0.978	0.198	110	0.9%
	5. Car (reference)	--	--	--	--	11701	90.7%

The analysis of the driver's injury severity variable, presented on Table 8, concluded that the worse the driver's injuries are, so too are the pedestrian's. In a case where the driver dies or suffers graves injuries, the 95% confidence interval states that the OR can be as high as 14.895.

Table 8 - Estimates on the determinants of road accident severity for the Driver's Injury Severity variable.

Variable	Description	OR	p-Value	95% Confidence Interval		N	Frequency
Driver's Injury Severity	1. Deceased/Severely Injured	6.482	0.000	14.895	2.821	29	0.2%
	2. Slightly Injured	2.323	0.000	3.203	1.687	359	2.8%
	3. Unharmed (reference)	--	--	--	--	12512	97.0%

The actions undertaken by the pedestrian prior to the accident play a key role in injury severity (see Table 9).

Table 9 - Estimates on the determinants of road accident severity for the Pedestrian's Actions variable.

Variable	Description	OR	p-Value	95% Confidence Interval		N	Frequency
Pedestrian's Actions	1. In the middle of the road	1.919	0.000	2.298	1.603	1589	12.3%
	2. Walking along the right lane	1.251	0.196	1.756	0.891	389	3.0%
	3. Walking along the left lane	1.313	0.198	1.986	0.868	230	1.8%
	4. Walking along the curb or sidewalk	1.340	0.012	1.687	1.065	974	7.6%
	5. In a pedestrian refuge on the road	0.869	0.711	1.822	0.414	108	0.8%
	6. In a road subject to construction work	1.456	0.272	2.843	0.745	84	0.7%
	7. Crossing a signalized passage with semaphore signalling disrespect	1.473	0.046	2.153	1.007	300	2.3%
	8. Crossing outside the pedestrian crossing, less than 50 meters from a pedestrian crossing	1.505	0.000	1.818	1.245	1656	12.8%
	9. Crossing outside the pedestrian crossing, more than 50 meters from a pedestrian crossing or where there is none	1.404	0.001	1.728	1.140	1272	9.9%
	10. Exiting or entering a vehicle	1.067	0.784	1.697	0.671	225	1.7%
	11. Appearing unexpectedly on the road from behind an obstacle	1.652	0.000	2.067	1.320	1114	8.6%
	12. Crossing at a signalized crossing (reference)	--	--	--	--	4959	38.4%

The reference considered is to cross the street at a signalized pedestrian crossing. The highest increase is reported by category 1, when the pedestrian is in the middle of the road, with an OR between 1.603 and 2.298. If the pedestrian is crossing the road at a crosswalk but disregarding the light signals (category 7) or crossing the road outside the proper crossing (category 8), the OR's are 1.437 and 1.505, respectively, indicating an increase on injury severity with these illegal actions.

When the pedestrian appears unexpectedly from behind a vehicle (category 11), there is also an increase on injury severity, with an OR ranging from 1.320 to 2.067. However and from in-depth accident investigation, has been found than this is a typical driver excuse if the driver is speeding. In accident investigation and for the determination of the legal responsibilities it's necessary to evaluate the dynamics of the accident and to check the driver's statement.

INJURY BIOMECHANICS

Statistical analysis provides an evaluation of the measures applied for improving road traffic accidents. However, this type of analysis corresponds just to a first phase of an investigation process and lacks fundamental information to increase the level of detail and understanding peculiarities associated with pedestrian road accidents, given the limitations imposed by the events to which the police do not have access on the accident site, such as the pre-impact vehicle velocities, the cause of the accident and the responsibility of their occurrence. So, the need arises for an in-depth investigation in order to analyze and have access to important and fundamental aspects of an accident, absent in a mere statistical analysis.

Engineering plays a key role, acting in two ways to solve pedestrian road accidents problems: after the accident, combining research with computer simulations in order to clarify how it occurred, isolating the key factors for its occurrence and determining responsibilities; in terms of prevention, recreating impact situations to analyze and evaluate the influence of certain parameters on the occurrence of pedestrian road accidents resulting in injuries, the effectiveness of the solutions/measures on the safety of pedestrians currently available or projecting new solutions in a simple, efficient and economically feasible way. The outputs of these reconstructions do not only target the scientific community. They also have a social interest where they may lead to the definition of measures and procedures in order to reduce the high rates associated with pedestrian road accidents as well as for dissemination by the entire population of the risk involved in certain type of situations identified as dangerous in these accidents, to try to mitigate the problem.

Impact biomechanics studies the forces acting on the human body, namely, impact forces, the effects produced by these forces and ways to reduce or eliminate the structural and functional damages on the body deriving from an impact situation [10]. The software PC-Crash can be used to evaluate the pedestrian's biomechanical behavior in an impact and analyze the injury severity based on acceleration levels obtained in the collision simulation. In its base are the multibody dynamics formulations, which are explained in detail in the literature [11] and on the software applied technical manual [12]. In practical terms, the injury level evaluation is done by using injury criteria applied to acceleration data withdrawn from the multibody models representing the human body in the impact simulation.

Injury criteria are a set of physical parameters correlated with the severity of the injury inflicted in the body area in analysis that indicate the potential for inducing injuries from the impact. These criteria are essential in the development of safety devices and for evaluating their efficiency. Concerning a fundamental vital area of the human body, the head, criteria to assess injury severity in an impact such as HIC (Head Injury Criterion) are available.

Head Injury Criterion

HIC is a criterion based on the head linear acceleration evaluated, for example, from biomechanical models, in a given interval, that is computed with the following expression:

$$HIC = \left\{ (t_2 - t_1) \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t) dt \right]^{2.5} \right\}_{Max} \quad (1)$$

In this expression the acceleration pulse *a(t)* at the head's center of mass is measured in multiples of the acceleration of gravity [g] in the time interval (t_2-t_1) that maximizes the HIC value. The maximum HIC value admitted, beyond which the resultant injuries are expected to be severe and permanent, requires t_2 and t_1 not to lay more than 15ms apart for a direct impact or an interval (t_2-t_1) of 36ms for an indirect one, with a HIC tolerance limit of 700 (HIC_{15}) and 1000 (HIC_{36}) for each case and considering the 50th percentile male [10,13].

Abbreviated Injury Scale

The Abbreviated Injury Scale (AIS) is a criterion based on an anatomic scale divided in six different levels that define the kind of injury and respective severity level for each part of the human body and the higher the AIS value, the higher the respective injury severity, culminating in death. There is a direct correlation between HIC and AIS (Figure 2) that enables the conversion of the head acceleration levels determined in computational simulations into injury severity.

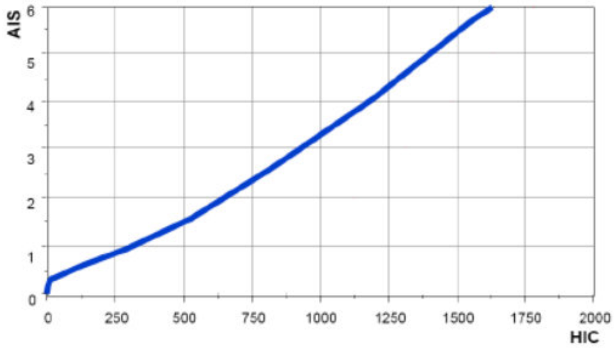

Figure 2. Correlation between HIC and the AIS scale [14].

This relation is used to evaluate the head injuries.

RECONSTRUCTION OF VEHICLE-TO-PEDESTRIAN ACCIDENTS

The methodology applied on the in-depth study of pedestrian accidents is an adaptation of the MAIDS methodology [8], following the same objectives, but in its application it's similar to the study undertaken by Clarke *et al.* [9]. The computational reconstitution of accidents is treated as an optimization process, where velocities and pre-impact positions are variable parameters. The procedures include the analysis of post-accident records handled by the police authorities, such as the accident sketch, pictures of the site and vehicles, as well as autopsy reports. The next step involves building the accidents computational layout based on this data and performing the computational simulations. Then one can estimate the pre-impact conditions, such as speed, position and course of the vehicles.

In a pedestrian run-over reconstruction, the only information collected by the police forces is usually the rest positions of the vehicle and the pedestrian's body. In most cases, one is seeking to determine both the impact speed and location. Thus, a problem arises: irregardless of the considered impact point, it's possible to determine an impact speed that throws the pedestrian to his recorded rest position. The differences between this wide set of possible solutions lie in the severity of the injuries sustained by the pedestrian, i.e., whether or not they are consistent with the contact forces. For each simulation, the pedestrian's injuries can be evaluated through the use of biomechanical injury criterions, which are then compared with the value stated in the autopsy report.

This work uses the Head Injury Criterion (HIC), which is based on the evaluation of the resultant head acceleration. For values greater than 700, serious and permanent injuries are to be expected. There is also a correlation between the HIC value and the Abbreviated Injury Scale (AIS) that enables the transformation of the HIC value in an AIS value, more easily compared with the autopsy report.

The case study represents a run-over involving a 59 years-old pedestrian and a BMW 318 during nigh time conditions. For the pedestrian's model, the anthropometric dimensions considered were a mass of 78,4 kg and height of 1,75 m, which correspond to the 50th percentile adult male [13] and the computational simulations were carried out considering a restitution coefficient of 0,1, a friction coefficient for the ground of 0,7 and a friction coefficient between the pedestrian and the pavement of 0,4. In the accident sketch provided by the police forces, multiple points of view can be seen. The witness report that the run-over occurred in a point situated 19 meters after the crosswalk, offering no estimation for the impact speed. The driver reports that he hit the pedestrian in a point 11.5 meters after the one reported by the witnesses, at a speed of 40 km/h. 14 meters after the point reported by the driver, we get to the pedestrian's rest position.

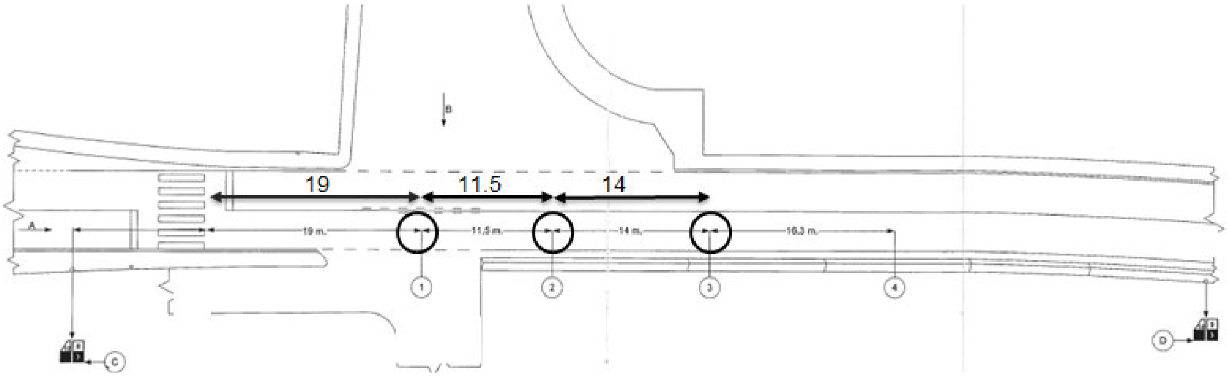

Figure 3. Accident sketch.

In a pedestrian run-over both the impact speed and impact location need to be determined. The problem is, no matter what impact location is chosen it's possible to determine an impact speed that throws the pedestrian to his rest position. The difference between all the possible scenarios will be given by the biomechanical injury criterions results. In this case, the pedestrian suffered skull and cervical injuries, fractured multiple ribs, both tibias and both humerus.

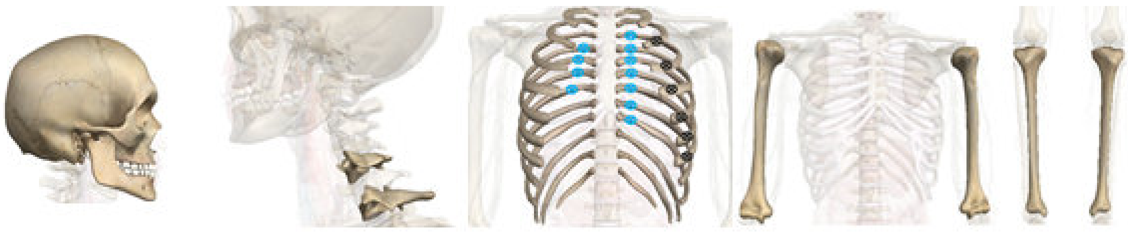

Figure 4. Bone injuries sustained by the pedestrian.

Bearing this in mind, three scenarios were investigated. In the first scenario, using the speed an impact point provided by the vehicle's driver, it was determined that neither the pedestrian's projection nor the biomechanical injury criterions were compatible with the ones described in the autopsy report. In the second scenario, still using the impact point reported by the driver but with an impact speed compatible with a projection to the pedestrian's rest position, the biomechanical injury criterions still were not compatible. In the third scenario, using the impact point reported by the witnesses with an impact speed compatible with a projection to the pedestrian's rest position, an AIS of 6, very different from the previous two scenarios was obtained. To determine the minimum speed compatible with both the injuries and the projection, starting on the impact point reported by the driver, several impact points behind it were considered, spaced 2 meters from one another. The injury results are presented on Table 11.

Table 10 - Injury output for the additional simulations.

Distance [m]	Velocity [km/h]	HIC	AIS
2	51	695.35	2
4	55.5	933.47	3
6	60	1360.26	4
8	63.5	1435.94	5
10	66	1697.32	5

It was determined that the minimum impact speed compatible with both the injuries and projection was of 60 km/h, 10 km/h, over the speed limit, in a point situated 6 meters behind the one reported by the driver. Furthermore, for this simulation there is compatibility between the vehicle's structural deformation and the injuries sustained by the pedestrian, namely, a primary impact between the lower limbs and the front of the vehicle and a secondary impact between the pedestrian's neck and the windshield, in which the cervical fracture may have occurred.

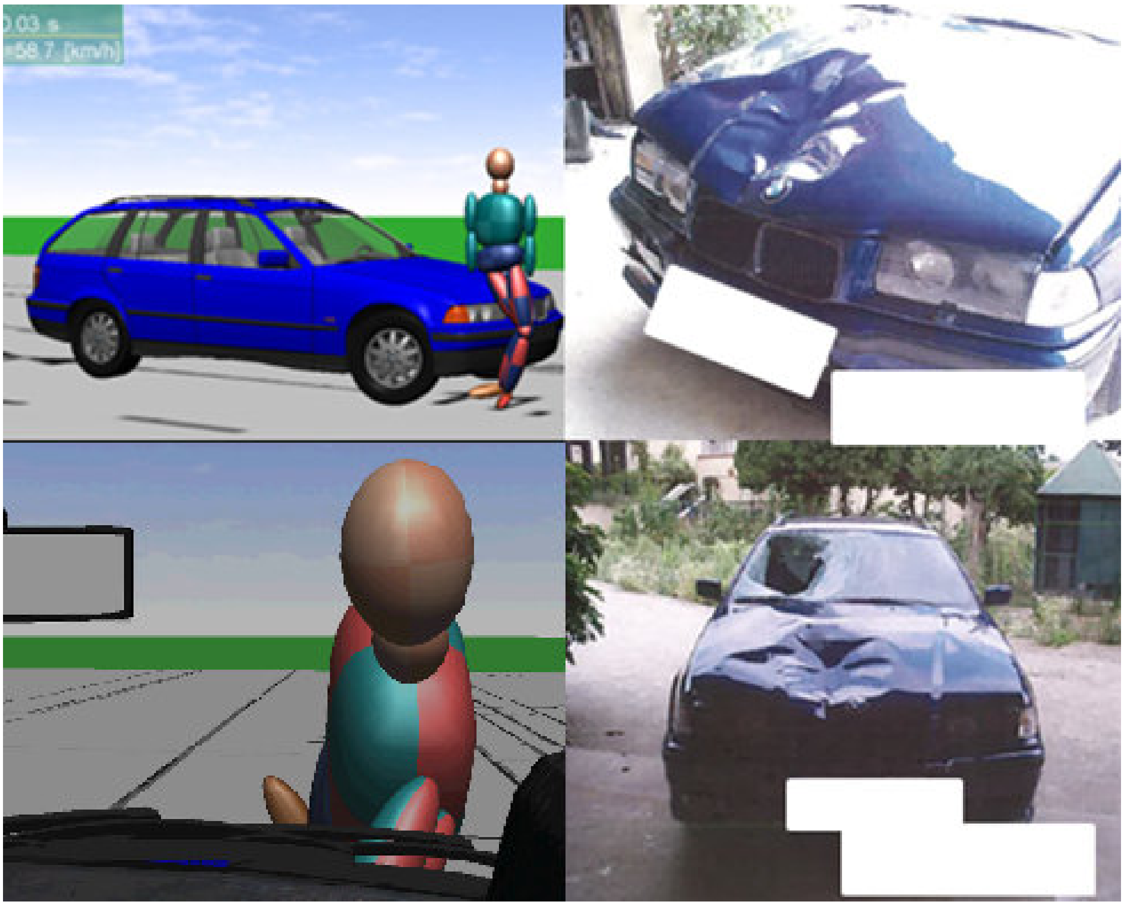

Figure 5. Compatibility between injuries and structural deformation.

The calculated impact speed is also well correlated with EES (Energy Equivalent Speed) databases, namely, the structural deformations are, seemingly, between the 60 km/h and the 70 km/h level, as it can be seen on Figure 6.

Figure 6. Reference EES values for pedestrian run-overs.

This methodology is widely used to determine the accident conditions.

CONCLUSIONS

This work established a connection between impact biomechanics, accident reconstruction and autopsy data for application to a real pedestrian run-over occurred in Portugal. Besides demonstrating the use and importance of injury biomechanics, it was intended to demonstrate the importance of computational reconstruction of road traffic accidents with the use of accident reconstruction software. The determined injury severity key factors may be used by police forces to more quickly assess the situation, establishing a theoretical framework between accident conditions and injury severity. The detailed comprehension of severe accidents involving pedestrians, injury mechanisms and their distribution in the pedestrian, translated into measurable data reveal themselves to be a valuable instrument to have a based perspective on the problem and identify the primary measures to apply, as well as in monitoring their efficiency. Preventive actions should combine education, law enforcement and engineering. Educational policies should influence and guide driving training and mainly the driver's and pedestrian's attitude more intensively by increasing their information about risk exposure and the responsibility of their actions. Police control interventions should be focused in reducing high risk behaviours, mainly, high speed driving and intensified in times and locations identified as critical. Engineering can act in the development of systems that increase pedestrian safety in case of an accident, like frontal airbags. Accident investigation and computational reconstitution are also important to clarify the responsibility of their occurrence, causes and to support safety measures.

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