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Keynote lecture: The Evolution of Accident Research

Abstract

This paper reviews briefly the evolution of the investigation of transport accidents from the early beginnings when individual events were studied but systematic data was not collected. In the transport modes other than on the roads, accident investigation early on, even of single events, was important in introducing safety improvements. Road accidents, however, evolved enormously with the growth of car ownership without any comparable political response to the consequent deaths and injuries, equivalent to what happened with the other modes. From the 1950s data bases started to contribute to our knowledge of the epidemiology of road traffic injuries, and in-depth sample studies have contributed much to the body of knowledge in the last 30 years. However, even the basic input and output variables of a crash, its severity and the seriousness of the outcomes in terms of injuries and their consequences are not complete or agreed upon. Issues of experimental design and sampling are discussed. It is proposed that the most important area for current research to address is the effect of population variations on injury outcomes. The need for the establishment of good data bases for active safety issues is emphasised with the consequent need for better links between the research community and the police.

Early Origins of Accident Research

The origins of transport accident research are probably related to the domestication of the horse, when man started to travel at speeds of 30–40 km/hr, some 50,000 years ago. Certainly the Romans were concerned with conflicts and accidents between pedestrians and chariots, and amongst other remedial measures decided on a rule of the roads which was to drive on the left side.

The investigation of individual transport accidents began to become a profession when we started to travel faster than a galloping horse, first by train and later by car. Thus in the 19th century railway accidents were sufficiently severe and sufficiently frequent to generate independent institutions responsible for accident investigation. In Britain for example, as well as a number of other European countries, a Railway Accident Investigation Board was created, independent of government, reporting directly to Parliament, with powers equivalent to those of the police. This was a precursor of the arguments as to the importance of independent crash investigation which continue to today in the air, marine and road sectors.

As these other modes of transport developed, accident investigation techniques also evolved. This was most noticeable with the rise of aviation, perhaps because flying is intrinsically a dangerous mode of travel, but also because as a predominantly passenger carrying commercial operation, there is an explicit contract between the carrier and its customers that the odds of arriving at their destination unharmed should be high. Thus commercial aviation became heavily regulated for safety reasons. Of particular interest today is that crashworthiness as a concept originated in aviation with the work of Hugh de HAVEN in the United States, and in 1942 John LANE in Australia suggested that aircraft should be certified in two ways, they should be both airworthy and crashworthy - hence the origin of the word crashworthiness.

The growth of road traffic with accompanying growth in crashes and injuries in the 20th century was by contrast a laissez-faire process. Responsibilities for crash investigation of road accidents rested in the first instance with the police, whilst general policies for road safety were usually attached to ministries of transport, but without clear mandates (or budgets) to provide safe road travel. Much folklore was generated about road accidents with policies aimed at changing driving behaviour through exhortation and training, without adequate evaluation of the effectiveness of such measures.

However, useful techniques evolved from the investigation of individual crashes. The examination of light bulb filaments, pedal prints, the application of Newtonian mechanics to calculate speeds from skid marks and the recognition by the legal process of the validity of such scientific analysis, began to set the basis for accident investigation as a legitimate forensic profession.

The Epidemiology of Traffic Crashes

The growth in car ownership in the latter half of the twentieth century was one of the greatest changes in the social and physical fabric of our society, affecting our landscape, the nature of our cities, our relationships with each other, our work, shopping patterns, health and recreations. Allied with that growth in individual travel was a similar rise in traffic crashes and injuries. Basic data bases developed, originating from the police, from insurance companies and from hospital records.

The variables used to describe the characteristics of accidents and injuries in those data bases were, and still are, poorly defined and often very subjective. Collision severity for example is defined in police and insurance records in a purely qualitative manner – minor, moderate, severe, or total destruction, describing the nature of the damage to a vehicle. The first injury severity scale was – no blood, blood, alive, dead.

Even today for example most countries classify their traffic casualties as having slight, serious or fatal injuries. Yet the definition of for example "serious" varies greatly from country to country. See Table 1.

In looking at the response of governments and society to the growth in traffic crashes and injuries over the last 50 years, what is striking is the absence of the health dimension until relatively recently. Road safety was a matter for ministries of transport, who often gave the subject a low priority compared with building traffic capacity and efficiency to cope with the growth in road traffic. Accident research has been held back by folklore and good intentions unsupported by good science, and objective evaluation of the effectiveness of countermeasures. Looking back it is extraordinary how the health sector historically has contributed relatively little to the knowledge base of road accidents and injuries. Such organisations as the German Society for Traffic Medicine have been an exception, but in terms of governmental priorities in the health sector traffic injury has been largely neglected. That, however, is beginning to change in the face of an increasing recognition of the social and financial costs of road crashes, which in most European countries amount to some 1–3% of GDP. Witness the more rational approach of many governments now in terms of setting targets for casualty reduction and evaluating the various strategies put in place to achieve such targets.

Country	Serious: Fatal	Slight: Fatal
Austria	8	32
Belgium	7	31
Denmark	8	7
Finland	4	12
France	4	13
Germany	12	33
Greece	1.6	13
Italy	8	23
Ireland	5	15
Luxembourg	7	14
Netherlands	8	26
Portugal	4	18
Spain	5	9
Sweden	7	18
United Kingdom	9	49
European Union (15)	7	23

Tab. 1: Ratios of fatal to serious and slight casualties in EU countries. E.T.S.C. 1997 [1]

Ad hoc Accident Research Studies

The main growth in traffic injuries took place between 1950 and 1980 in most of Europe and in that period there were many individual contributions to our knowledge of the details of traffic accidents and injuries. In Germany for example GOGLER in Heidelburg started to bridge the gap between medicine and engineering by employing an engineer from Volkswagen to conduct detailed investigations in to how injuries were caused [2]. Volvo in Sweden established a programme to find out how Volvo cars actually performed in the real world. The German and Swedish insurance companies set up data bases to improve their knowledge of these events called road accidents gave rise to the costs which they were insuring. Small individual efforts at universities in Denmark, the UK, Sweden and elsewhere began to initiate in-depth studies to examine crash performance of cars, which lead to major improvements in such items as restraint design, door latch performance, the switch from toughened to laminated glass for windscreens, steering column performance and many other items. Such studies were often based on small samples of crashes, using limited statistical techniques and relatively primitive variables. It was commonplace for example for each research team to develop their own injury severity scale, using such words, as minor, moderate, life-threatening, slight, serious, severe, disabling in many different ways, so that there was little compatibility between studies. The almost universal adoption of the A.I.S. has greatly diminished that problem, although its correct application varies significantly even today.

One of the most important events in the evolution of road accident research was the establishment of the United States Federal Motor Vehicle Safety Standards in the late 1960s and early 1970s. That created a need by other governments and the car industry worldwide to find out more about the developing problem of road traffic injury, and as a result many research programmes were initiated and new data bases evolved.

The Rise of Data Bases

Most countries began to recognise the limitations of police data, and intermediate level data sets, and began to fund more detailed crash investigation programmes. The most noteworthy has been the rise of the NASS/GDS system in the United States, evolving in the late 1970s and especially important as it is freely accessible to anyone. That data base, because it is open to anyone, has probably given rise to more accident research publications and contributed more knowledge to the subject than any other. Governments and other institutions who wish to maintain proprietary control over their own programmes should be persuaded to open their own data to others for more general use, by following the example of the US government.

The attraction of more accurate and more comprehensive data lead to the establishment of a number of in-depth programmes around Europe, notably in France at INRETS, in Germany with GIDAS and in the UK with CCIS. In addition a number of car manufacturers instigated their own in-house investigation teams. A similar move in the United States has lead recently to the CIREN programme. Common to all these activities was the recognition of bringing together as a team, engineers and doctors, together with other specialists, because fundamentally both disciplines are needed. Such research has been useful in evaluating the effectiveness of vehicle design changes, restraint benefits and limitations for example, understanding specific mechanisms of injury, as well as drawing attention to emerging problems and new priorities. Such in-depth studies however always suffer from small sample sizes and skewed selection criteria. For example the CIREN programme is based on cases where an occupant is admitted to a major trauma centre. That in itself means that all the crashes examined involve a major injury, which limits the general applicability of any resulting analysis.

Beyond these data bases there are investigations of individual crashes, usually involving either large numbers of casualties or well known people. Such examples are major bus crashes such as the Tuen Mun Road Bridge accident in Hong Kong which killed 22 people, the M42 motorway accident in the UK which involved 170 vehicles, and the accident in Paris in which Princess Diana was killed which has resulted in major inquiries in two countries, costing so far several million euros. In addition product liability claims and other legal consequences of road crashes are leading to very detailed investigations and reconstructions beyond the resources of most academic or government institutions. Such events however can contribute significantly to the body of knowledge of accident research. An example of such a complicated reconstruction is illustrated in Figure 1.

Figure 1: An example of a reconstruction of an intersection collision between a tractor trailer combination travelling at 55mph and a car pulling out of a side road at 20mph. Because of the difficulties of accurately matching the initial points of contact with both vehicles moving, the reconstruction is made with the tractor trailer stationary at an angle of 18.5 degrees to the line of travel of the car. The car is pulled at a yaw angle of 69 degrees into it at 55mph. This is achieved by creating a very low friction surface between pads under the car's wheels and the metal surface of the

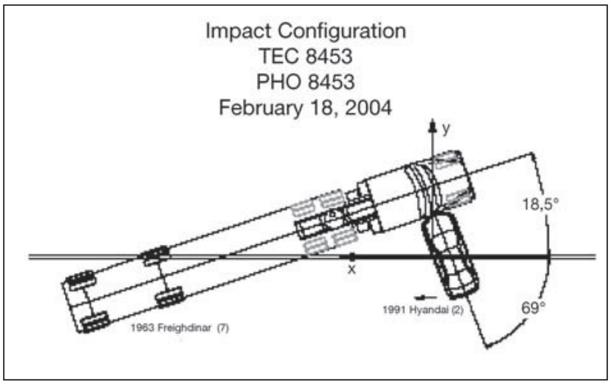


Figure 1

test track covered in soap. It allowed the car to engage solidly with the lateral aspect of its left front wheel against the tractor unit's right forward dual driving wheels, as occurred in the accident at the appropriate relative velocity and angle.

Current Issues

Basic Core Parameters

Fundamentally there are two basic variables in accident research. The input variable is the severity of the event, the outcome is the consequent injury or injuries. In spite of many attempts over the years these two variables are still poorly defined and imprecise. For the severity of the crash the most used variable in the change in velocity, Delta V. This variable is usually derived from measurements of crush of the vehicle structure and some knowledge of that structure's stiffness characteristics based on various crash tests. However, that process involves a number of approximations because any given impact in an accident differs from whatever standard crash test data that are available. The process itself involves measurements of the extent of the crush which in itself in only an approximation of the way in which a structure has been loaded. At higher and lower collision speeds than those covered by the standard crash tests at 50km/h, there is a small amount of data from experimental tests available. For narrow object impacts, particularly into the sides of vehicles, there is little available, and at low impact speeds where elastic rebound becomes important, coefficients of restitution are seldom known with any accuracy. Newtonian momentum and energy exchange calculations (using the EES for example) can be helpful, but this basic variable which defines the severity of a collision is still imprecise.

A second order problem is present in that such a parameter as the Delta V (or EES) is usually calculated as acting through the centre of gravity of a vehicle. The Delta V for a particular occupant, in the case where there is major rotation during the crash phase may be very different from which is occurring at the centre of gravity. Also if there is significant intrusion, the specific applied loads to an occupant and hence his Delta V within a zone of intrusion, can be greatly different from which is occurring at the centre of gravity. This applies frequently in the case of occupant on the struck side in a lateral collision for example. These factors are often ignored or not analysed in many studies.

A number of alternative parameters for assessing collision severity have been used. Mean acceleration is one example, or peak acceleration, derived from the mean acceleration by assuming a given pulse shape for the deceleration of the vehicle is another. Seat belt loads as derived from the load limiting devices in seat-belts has been used successfully in some specific instances [3], but in general none of these alternatives is totally satisfactory.

Crash recorders of various levels of complexity are now becoming widespread. Recent work by YDENIUS has demonstrated that there is a reasonable correlation between mean and peak accelerations, and that acceleration correlates well with injury risk. The duration of the crash pulse does not appear to be related to any increased risk, at least in comparing crashes with a pulse duration over 110ms compared with those of a shorter duration. Hence the use of Delta V, at least for collisions with roadside objects having long duration crash pulses is not a satisfactory parameter for assessing collision severity and injury risk [4].

Fortunately, with the widespread adoption of event recorders integrated into the central processing unit of a car's sensing systems there is now an opportunity developing for the recording of specific time/deceleration/direction histories of a collision. Hence there is also an opportunity for developing data bases in which better parameters for assessing crash severity are recorded. This technology is currently available but its widespread adoption depends more on social and legal issues than on technological complexity. However, it is already providing an interesting check on the accuracy or otherwise of conventional reconstruction techniques.

The second core parameter is the measurement of outcome from an accident, in terms of injury severity. In many ways this is a more complicated issue because injury severity has many dimensions. These can be threat to life, amount of tissue damage, loss of quality of life, cost of treatment, loss of physical function either temporary or permanent. The preferred scale which has been universally adopted is the Abbreviated Injury Scale (A.I.S.) which has the dimensions of threat to life and amount of tissue damage. This is an ordinal scale with categories 1 to 6 described as minor, moderate, serious, severe, life-threatening survival probable, life-threatening survival uncertain, and currently untreatable (note that death is not a category). The latest 2004 version, like its predecessors, is a descriptive scale, essentially a listing of over 2000 injury descriptions and their agreed severity. This has the great virtue that it allows injuries to be classified in the same way by anyone, anywhere, making different data bases comparable [5]. This latest version of the A.I.S. is also linked to the Functional Capacity Index (FCI) which adds the capability of assessing the disabling, or loss of function consequences of a given injury as well. It is however, not a numerical scale, an AIS 4 injury is not twice as severe as an AIS 2 injury. You cannot produce an average AIS number of say 3.6 for a sample of patients, although some researchers have erroneously tried to do so.

In accident research the A.I.S. has proved to be an extremely useful parameter, but the conclusions drawn from its use have to be considered carefully. Is a brain injury of AIS 2, equivalent to a knee injury of AIS 2? This is clearly not the case when other dimensions are considered. The addition of the FCI will facilitate this distinction and allow multidimensional analyses, but it still illustrates the limitations of how to scale this extremely complex issue of the outcome of a collision.

Experimental Design and Sampling

Often data collection systems and projects are set up to provide insights into various aspects of traffic crashes without any clear numerical predictions being made as to the minimum number of cases needed to establish significant differences between specific outcome variables. To take a current example, what benefits are obtained by the addition of pretensioners to seat belts? Assuming a data base of crashes of all levels of injury severity to restrained occupants sampled at random, some in vehicles with pretensioners and some without. How many cases would be needed to establish a significant difference at the 5% level between the proportions of injuries at various injury severity levels? Clearly there are confounding factors such as age, gender, BMI, crash severity, presence of intrusion, collision type, presence or absence of airbags, etc. Examination of the data base numerically to allow for such factors will probably show that a surprisingly large number of cases will be needed to be collected before a comparable subset of cases is available. Likely several thousand cases in the study design would be needed to meet the minimum cell sizes for a statistical difference to be detected.

With all in-depth accident data bases some sampling occurs. Usually such sampling is biased towards the more severe end of the injury spectrum, covering for example all fatalities in a given region in certain types of accident, a proportion of hospital admission cases and a smaller proportion of slight injury and damage only cases. To produce a sample of cases representative of the total population requires the introduction of weighting factors. Such factors depend on a knowledge of the total number of cases occurring in a given area which itself may be difficult to obtain. Also if a weighting up process is used then a few unusual cases in one cell may produce major distortions in a weighted sample. Purists point out that such weighting of samples should always weight downwards from the least number in a given category.

Many of the important insights into the characteristics of accidents and their consequences come from longitudinal comparisons between data sets which have been collected over several years. The NASS-GDS system in the United States was established in 1976 and continues to today. It has allowed countless studies of a comparative nature to be made where the introduction of new technologies or new regulations can be evaluated for their effectiveness. Europe has lagged badly in this regard in that no comparative systems exist on a European basis, and at national level such studies as are conducted are less comprehensive and often subject to changes which make longitudinal time series analyses difficult.

Injury Severity Risks and Population Variations

Experimental biomechanics has given us the standards parameters for the outputs from a dummy in a crash test – HIC <1000, Chest acceleration <60 g, Femur loading <1020 kg. These are mainly derived from experimental studies based on instrumented cadaver testing. Figure 2 shows such data for the risk of an AIS 4 compared with the HIC. Such data has been expanded to give insights into risk levels for other levels of injury severity in figure 3. What is largely missing from such analyses is the effect of population variations relating to the living

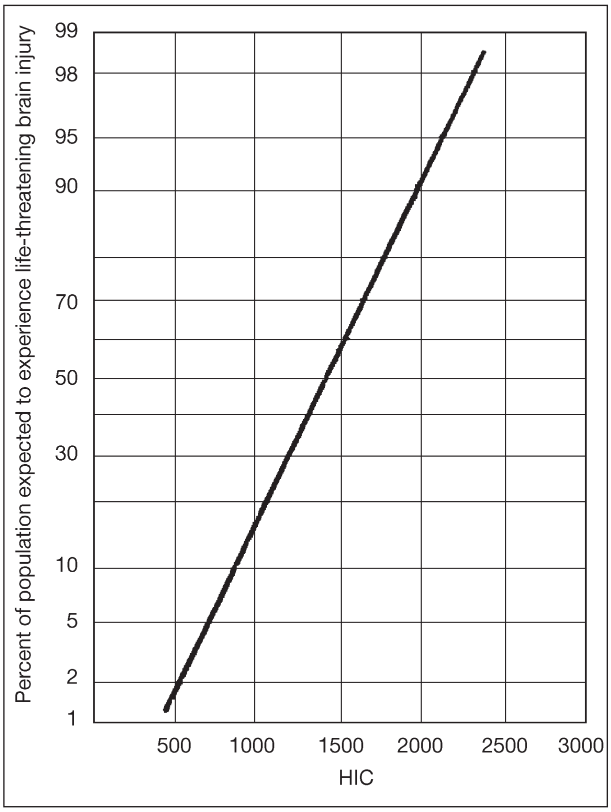
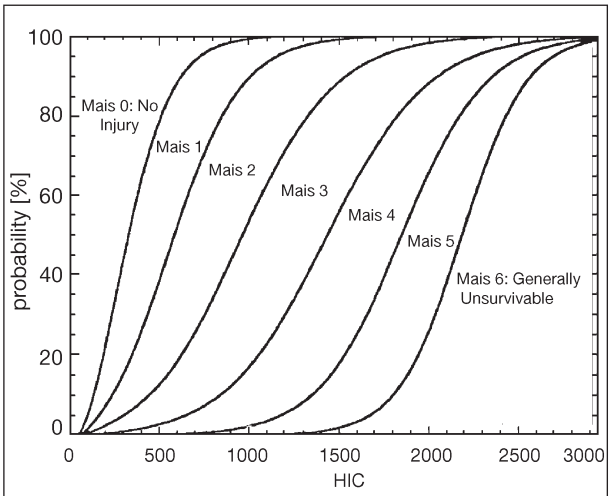


Fig 2: Risk for AIS 4 or Greater versus HIC Values



Prasad, P. and Mertz, H. J. The Position of the U.S. Delegates on the Use of the HIC in the Automotive Environment. ISO WG6. SAE 851246 Warrendale, Pa. 1985.

Fig. 3: Probabilities of Injuries at Various AIS Levels versus HIC Numbers

population having crashes in the real world. With the introduction of adaptable restraints, one of the most useful contributions which accident research can make at present is to describe the consequences of real population variations on injury risk. The key parameters are age, gender, height, weight, BMI. But there are probably subtle

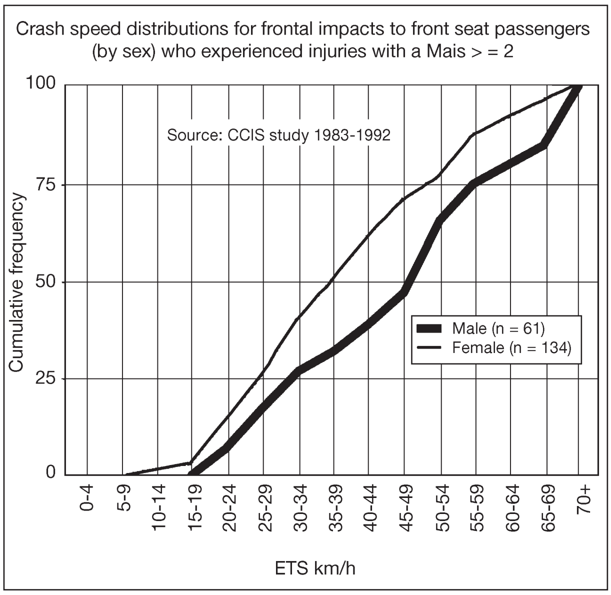


Fig. 4: Relationship of Gender to Delta v for MAIS ≥2 for Restrained Occupants

combinations of these parameters which come together to produce especially high or low levels of risk, together with additional factors such as physical fitness, state of health, alcohol and drug intake, clothing, and other factors. Small female drivers currently have to sit close to the steering wheel, and thus have been found in accident studies to be at higher risk of airbag related injuries in crashes. But tall, thin males have been found to be at more risk of belt related chest injuries than smaller males, probably because the path of the shoulder belt is lower across the rib cage and is thus loading the lower ribs which can be fractured more easily than those higher in the rib cage where the attachments to the sternum and the spine are more substantial and less cartilaginous [6].

Figures 4 and 5 illustrate some accident data which examine age and gender [7]. Gender differences for example show that a difference of some 10km/h is present between males and females to produce the same frequency of injury exposure. But whether such a difference is really the result of a gender difference or whether it is more of a second order consequence of sitting position and posture, and other factors is unclear.

These factors are of importance to the development of adaptable or smart restraints but they are particularly important in the context of the more general yardsticks which are used in designing crashworthiness into car. Current car design is largely driven by the need to obtain good ratings under the EuroNCAP scheme. For frontal

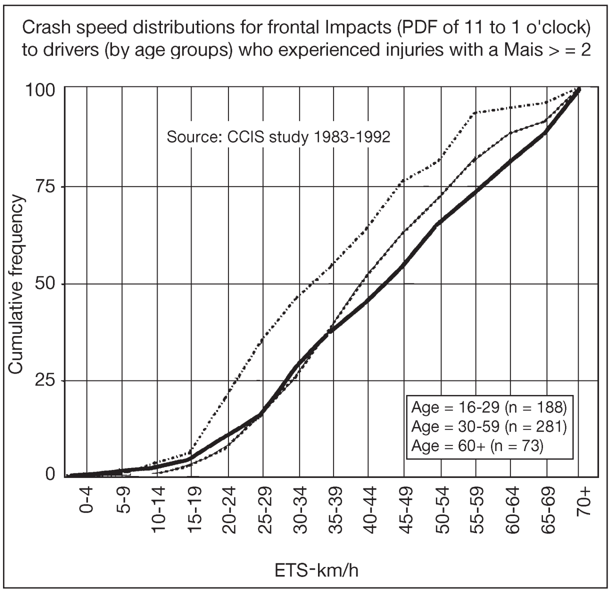


Fig. 5: Relationships between Age and Delta V for MAIS ≥2 fotr Restrained Occupants

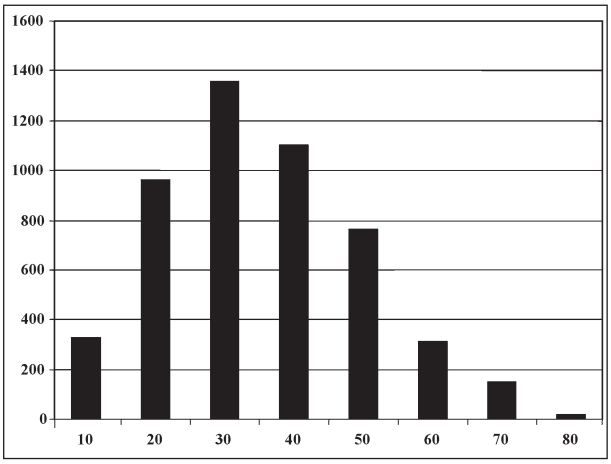


Fig. 6: Delta V in Km/h for AIS ≥3 for Restrained Occupants in Frontal Collisions

crash protection for example 64 km/h deformable offset barrier test sets the gold standard for protection in that type of collision. Accident data show that most collisions which cause AIS >3 injuries occur at Delta V severity which are much lower, figure 6. Real world data suggests that better design might be achieved by conceivably lowering the crash severity speed in the test but, more importantly lowering the acceptable injury criteria to perhaps HIC <750, chest accelerations <50 g, and femur loads <750 kg. This is one example of the great importance of real world accident analysis and its effects directly on vehicle design.

Active Safety Data Bases

If you compare the resources and expertise which are deployed when serious and fatal crashes occur in the aviation, rail, maritime and industrial contexts, with what occurs with serious road accidents, even in the relatively advanced countries of the EU and North America, there is clearly a huge difference in approach. The sheer magnitude of serious road accidents has led to a fatalistic response at the political level, supported by a history of folklore about road accidents which still lingers on. The general acceptance of the systems approach coupled with the aspirations of Vision Zero as developed in Sweden, are now being reflected in most European countries, but the necessary data bases to actually gain more knowledge about causal factors and how they come together to cause road accidents are only just being established and we will hear more of those efforts in this conference. Active safety brings together other disciplines than automotive engineering and medicine, most importantly human factors engineering and highway design and management. But the need for good experimental design, well planned sampling structures, clarity in the use of the variables to be examined and hence adequate resources to obtain meaningful and statistically justified results are just as important as in other types of accident research. Accident research over the last 30 years has focused mainly on the general epidemiology of accidents and crash performance related to injury outcomes, such work must continue as there are many useful issues to examine, but active safety has been neglected and now is the time to change that. Hopefully resources will be available to make that happen.

One obvious, existing source of data is the information collected by the police throughout the EU. In many countries the level of expertise of the police and forensic scientists and engineers available and used, at least where fatalities are concerned, is very high. Yet such material is seldom used for research purposes or published in normal scientific journals. This represents an opportunity where the research community needs to cooperate with the police, take advantage of their expertise and develop the available data sources, only through working with the police and emergence services will good data bases be developed.

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