FIELD DATA - A BASE FOR THE DEVELOPMENT OF SAFE VEHICLES

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ABSTRACT

Transportation of people and goods has increased gradually over the years with the consequence of injuries and fatalities to people in the transport system. To describe the injury problem in the transport system, and to understand the mechanisms why accidents and injuries occur, require an extensive collection and analysis of field data. Field data has over the past fifty years served as a very important base for the development of safe vehicles and has strongly contributed to correct priorities, an improved understanding of the complex mechanisms, and provided the opportunity to evaluate the impact of measures taken. This article aims at providing a short overview of how field data is used as the basis for the development of safe vehicles. A few examples are highlighted to illustrate the development, although without claiming to provide a comprehensive picture.
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Keywords: Accidents, accident reconstruction, databases, epidemiology, cost benefit analysis.

OVER 1.2 MILLION PEOPLE DIE EACH YEAR on the world's roads, and between 20 and 50 million suffer non-fatal injuries, according to WHO's global status report on road safety: time for action (2009). In the same report, WHO predicts that road traffic injuries will increase to become the fifth leading cause of death by 2030.

Actions related to safe transport has been taken for centuries. The Romans designed road environments with one-way streets, parking laws, and pedestrian crossings (stepping stones), to improve the safety for road users. During the last century, the need for and means of transporting people and goods has changed significantly. With increased transport, the number of injuries and fatalities in traffic has also increased significantly. However, even before the age of motorism, road accidents were a problem. In Britain for instance, there were 1,589 traffic fatalities in 1875, mostly involving horse conveyance of some kind (Cummins, 2003). The first recorded automobile fatality occurred in 1869 in the Irish Midlands, where the scientist Mary Ward fell from a steam carriage and was killed by its heavy iron wheels (Fallon et al., 2005). Other early traffic victims where Henry Lindfield from Brighton, who died in 1898 after crashing his motorcar into a tree (Roberts, 1998), and Bridget Driscoll, Crystal Palace, who was killed in1896 by a car during a demonstration (Porter, 1998).

How can field data support the process of vehicle development? Firstly, there must be a holistic approach where there are sufficient means to analyze different aspects carefully. A structured working process is required, to help understand the influencing mechanism, to set priorities, and evaluate the efficiency of the developed safety-enhancing solutions. Haddon (1968) created a matrix for the conceptualization of the etiology of injuries resulting from motor vehicle crashes, Figure 1. The Haddon matrix has been widely used in describing the holistic approach to vehicle safety issues, and is still a relevant tool.

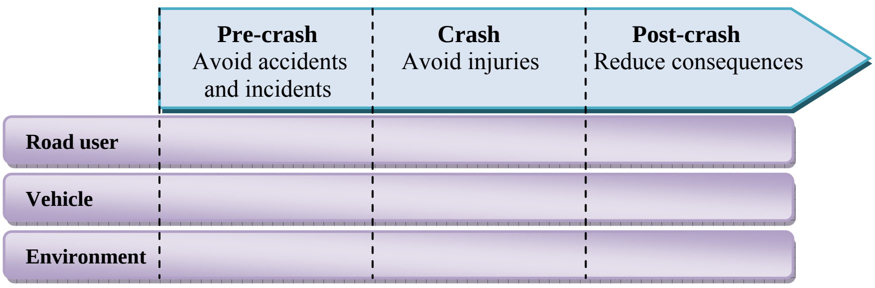

Fig 1. Overview - based on the Haddon matrix principles

The overall objective for the traffic safety measurements may be to avoid/reduce accidents/incidents, avoid/mitigate injuries to road users, and reduce the consequences of a crash. Experience from actual crashes functions as a driving force for safety development work, and provides a more robust analysis covering situations other than single crash tests.

The development work can be described as a circular motion, Figure 2, as an early description of the working process presented by Volvo (Almqvist et al., 1982). The first phase is the real traffic environment. In this phase, field data provide the knowledge and analysis, which forms the basis of the vehicle development process. The second phase is the actual vehicle development phase. The products/systems are evaluated in the simulated laboratory environment where developed physical and virtual methods and tools are used. The next phase is the production phase. After production, the new products are used in the real traffic environment, where their properties can be evaluated using field data.

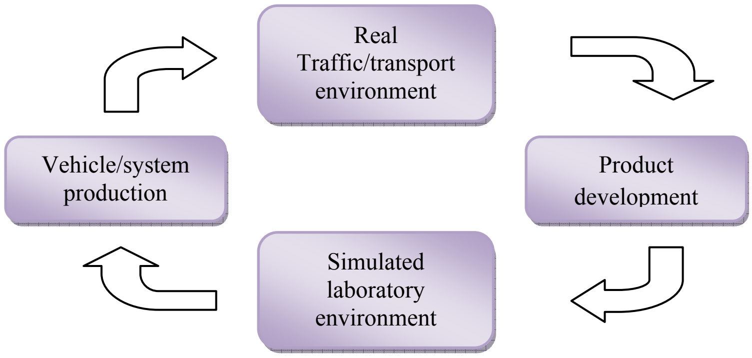

Fig 2. - Overall work process

This article will follow the principles of this outline, focusing on the real traffic/transport environment as well as the simulated laboratory environment.

REAL TRAFFIC/TRANSPORT ENVIRONMENT

Field data forms the basis of the vehicle product development process. It provides the basis for setting requirements, for prioritizing, for understanding the mechanisms, and for effect analysis. Field data provides the possibilities to:

- Understand the extent of the accident/injury problems
- Describe accident/injury related distributions
- Obtain representative data to be able to prioritize
- Understand different types of mechanisms
    - Accident causing mechanisms
    - Injury mechanisms
    - Driver action/reaction/adaption
- Evaluate the characteristics/effectiveness of vehicles/systems/components.

Depending on the type of questions to be addressed, different types of field data are required. To understand the mechanisms that explain why accidents and injuries occur, detailed data of high quality must be collected and analyzed, Figure 3. Depending on the availability of data, costs, research questions, etc. data is collected at different quality/quantity levels, e.g. by the police, multidisciplinary teams, etc. Accident data is collected directly on scene shortly after an accident, or retrospectively.

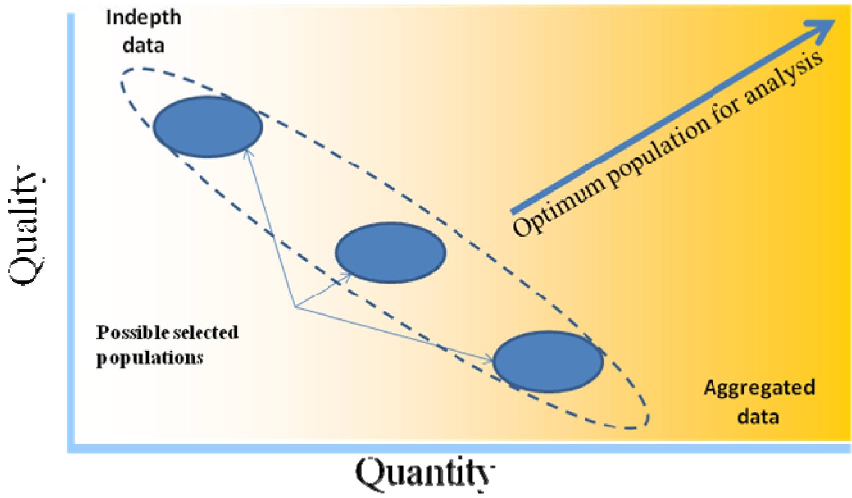

Fig 3. - Types of field data

To make accurate priorities, a good knowledge of how often different types of accidents and injuries occur is essential. Knowledge of the distribution of data is necessary, and requires some level of aggregated data. To be able to study all accidents that occur with high quality may be an optimum population analysis, but this is often not realistic, or perhaps not even possible, for various reasons. A multilevel approach with a combination of quality and quantity data on different levels may be a good way to achieve an analysis that allows in-depth knowledge combined with good data representation.

In order to make correct priorities, the information which should be the basis for priority must be representative in some sense, i.e. that the collected data, as accurately as possible can provide fair and accurate answers to the questions that need to be answered.

With low risk of generalization, it is possible to say that no two accidents are the same. There are a host of different factors which influence events before, during, and after an accident, and which affect the consequences an accident can have. However, to facilitate the analysis of field data, it must be categorized in groups which reflect important factors influencing the outcome but still provide a sufficiently large basis for analysis for each group. Categorization can be done at different levels, e.g. scenario level, vehicle level, occupant level.

ACCIDENT PREVENTION DATA - COLLECTION AND INTERPRETATION: The first step to avoid adverse consequences from transportation in terms of injury and death is to find ways to prevent accidents from happening. Since the early 1950s there have been many attempts to understand the causing factors of accidents. There have been accident investigations on different levels, e.g. multidisciplinary teams with experts from different fields. Many of the investigations focused on the traffic environment have been on special environment locations, e.g. intersections or certain road sections. The Traffic Conflict Technique has been an important tool for such studies and is based on early research in General Motors' laboratory in Detroit in the late 1960s, to identify vulnerabilities in the design of vehicles (Perkins and Harris, 1968). The use of this technique developed gradually in different parts of the world. The technique itself depends on the ability to register the occurrence of near accidents directly in real-time traffic (Archer, 2001). During the 1970s and 1980s, the Swedish Traffic Conflict Technique was developed at Lund University (LTH) in Sweden to the current level (Hydén, 1987).

In recent years, new technologies have opened new possibilities for understanding the causes of accidents. Data logs from the vehicle, the driver, and the surrounding environment, where data is collected continuously during normal driving, will open new possibilities to understand accident causation, but also implicate major challenges in the development of methods for collection, storage, and analysis of data.

Some of the world's largest field databases will be those with naturalistic data. Within the next few years, large amounts of recorded data and video from real-life crashes, near-crashes, incidents, and normal driving will become available for analysis (Victor et al. 2010). Some data is already made publicly available, or will soon be, e.g. 100-Car Study (http://www.access.vtti.vt.edu/) and Distraction in CVO study (Olson et al., 2009).

When naturalistic data is used for evaluation of vehicle system it is often called Field Operational Tests FOT), while when this type of data is focusing on causation of crashes and incidents, it is called Naturalistic Driving Studies (NDS).

The (FOT, which will provide knowledge about the effectiveness of Advanced Driving Assistance Systems (ADAS) to prevent the occurrence of accidents, will be of great importance in the future. In FESTA (2008), the FOT is defined as “a study undertaken to evaluate a function, or functions, under normal operating conditions in environments typically encountered by the host vehicle(s) using quasi-experimental methods”. FOT thus aims to study the effect of new systems and features that are installed in vehicles. This is conducted in the normal operation of a vehicle for a longer period of time, without specific instructions to the driver, where data from the vehicle, video camera recordings, etc. is automatically stored, and the system and/or feature to be evaluated can be enabled or not.

A Naturalistic Driving Study (NDS) focuses on the explanatory factors associated with crashes and the possibility to predict involvement in crashes (Victor et al., 2010). An important prerequisite in NDS is that normal vehicles are driven in regular traffic and the instrumentation for data acquisition is very discreet, and affects the driver’s normal run-time environment as little as possible. The 100-Car Naturalistic Driving Study was the first instrumented vehicle study undertaken with the primary purpose of collecting pre-crash naturalistic driving data. The study was carried out by Virginia Tech Transportation Institute (VTTI), involving over 100 individuals who volunteered to drive their own (or leased) vehicles with specialized instrumentation for 12-13 months in the Northern Virginia/Washington metropolitan DC area (http://www.vtnews.vt.edu/story.php?itemno=833). Another ongoing study, established by the US Congress and commissioned by Strategic Highway Research Program (SHRP2) will involve 2000 cars over a three year period.

In planning and implementing a FOT/NDS project, it is essential to involve the entire chain: data collection, data storage and analysis, see Figure 4. In all areas, there have been a substantial development of the methods and tools in several finished projects, FESTA, 2008, SeMiFOT (Victor et al., 2010), and in ongoing projects such as SHRP2, and EuroFOT.

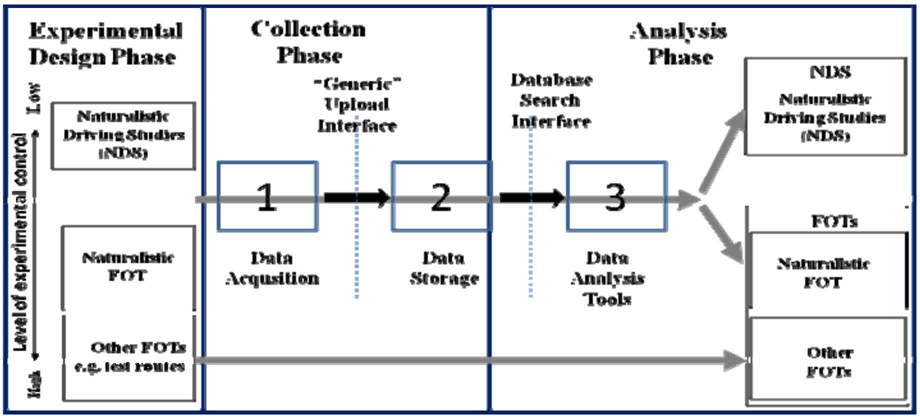

Fig 4. - Method Chain in Relation to NDS & FOT

In FOT/NDS studies, large amounts of continuous data is collected from the vehicle, the environment, the drivers, video recordings, etc.. How the data is prepared and stored significantly affect the possibilities for efficient data analysis. The large volumes of data require a development of the methods which automatically identifies interesting events. It is also important to define which types of event that are interesting/relevant to study.

In the SeMiFOT project, a Crash-Relevant Events Analysis Method for Accident Causation Research was developed and discussed (Victor et al., 2010). Here, crash-relevant events (CRE) are defined as “time segments which contain a particular occurrence that predicts or identifies a crash”. A coding scheme for CRE severity and event typology, including definitions, was developed. Figure 5 (Source: Sweden-Michigan Naturalistic Field Operational Test (SeMiFOT), Phase 1: Final report.) illustrates the CRE categories in relation to event types and normal driving. It has also been found that video data is an essential component in the validation of CRE (see below) and analysis of driver behavior.

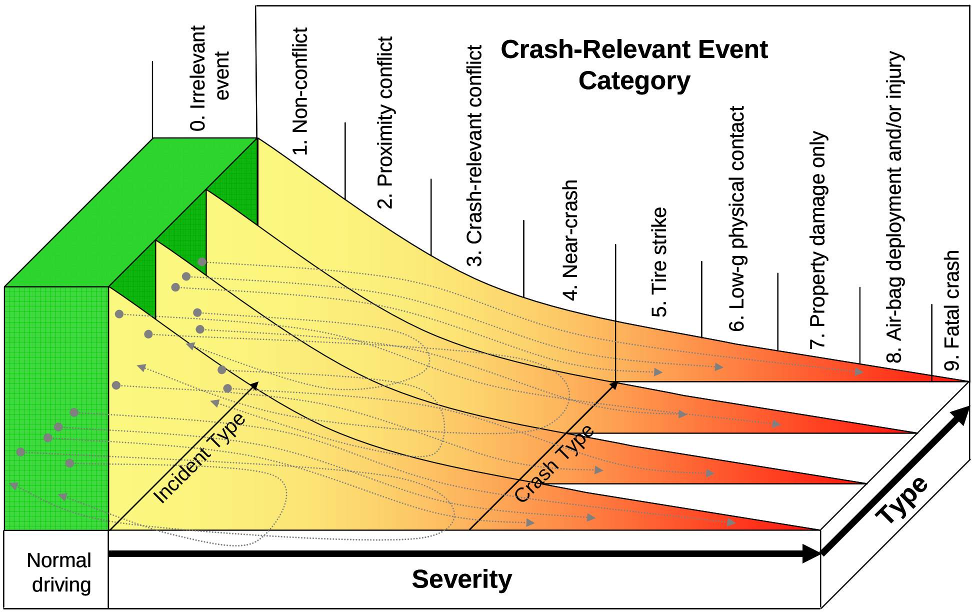

Fig. 5. - The SeMiFOT crash-relevant event severity categories.

OCCUPANT PROTECTION DATA - COLLETION AND INTERPRETATION: To promote the reduction of injuries an important initiative, the Vision Zero, was introduced in Sweden in 1995, and adopted as a parliamentary resolution in 1997, to become the foundation for road safety operations in Sweden (Anders Lie and Claes Tingvall, 2009). The Vision Zero Initiative is based on the ethical standpoint that no one should be killed or seriously injured for life in road traffic.

What is the cause of the occurrence of injuries? They are caused by some kind of violence to the body of the road user. When analyzing accident data, it is important to be able to define the violence to which the occupant has been exposed in a given situation. This is a highly complex concept and is difficult to describe in a clear-cut manner. A host of different factors affect the injury mechanism to which the occupant is subjected, and also the severity of the injury. A good understanding of the type and level of violence is a necessary base for the evaluation and analysis of the mechanisms which cause the injuries, Figure 6.

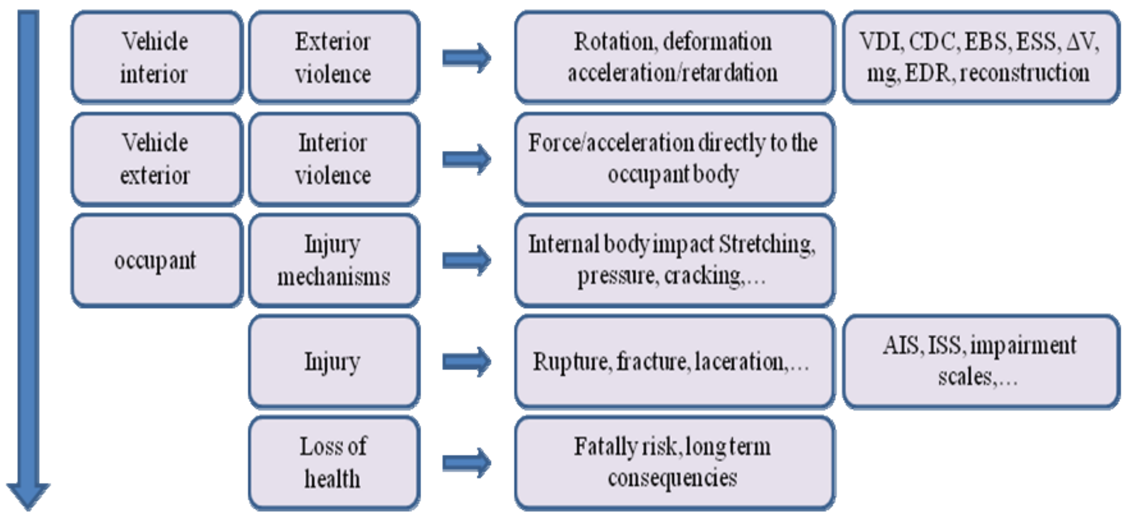

Fig. 6. - Violence and injury

Marquardt suggested that ideally, a measure of impact severity would be such that all accidents with the same impact severity would produce the same injuries for a given occupant (1977).

During the last 50 years, a lot of different measures have been proposed and used in accident analyses. The quality of measures has gradually increased based on increased knowledge and technical improvements, se Figure 7.

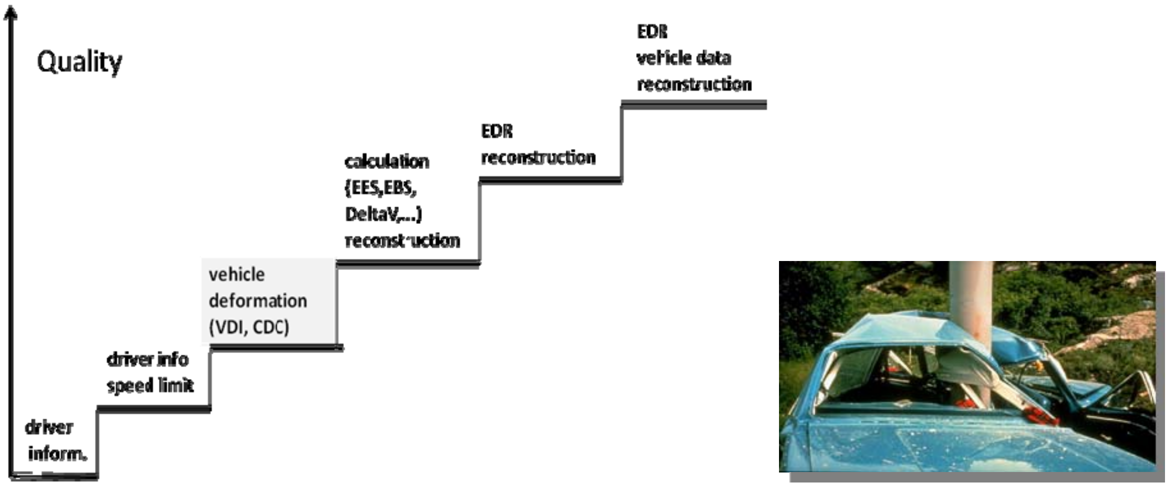

Fig. 7. - Estimation of accident violence

Very early, information from the driver and/or witnesses was used, sometimes in combination with speed limit information. The development of vehicle damage scales in the 1970s and 1980s gave some means to estimate the degree of violence. In the 1960s, the Motor Vehicle Manufacturers Association in US pioneered the first attempts to get investigators together to define their needs for describing vehicle deformation, and to work on solutions (Nelson, 1981). This resulted in development of the Vehicle Deformation Index (VDI) and later the Collision Deformation Classification (CDC). Several measures based on the amount of energy the vehicle structure absorbs during an impact were developed. Equivalent Barrier Velocity (EBV) is obtained from the energy that is required to deform the vehicle (Mackay, 1968). Other similar measures include the Equivalent Test Speed (ETS), Barrier Equivalent Velocity (BEV), Equivalent Barrier Speed (EBS) (Mackay and Ashton, 1973), and Energy Equivalent Speed (EES) (Burg and Zeidler, 1980).

Campbell provided a basic methodology for deriving a relationship between EBS and the residual deformation in vehicle resulting from barrier collision in the laboratory (1972, 1974). This technique was further developed by Nilsson-Ehle et al. (1982), see Figure 8.

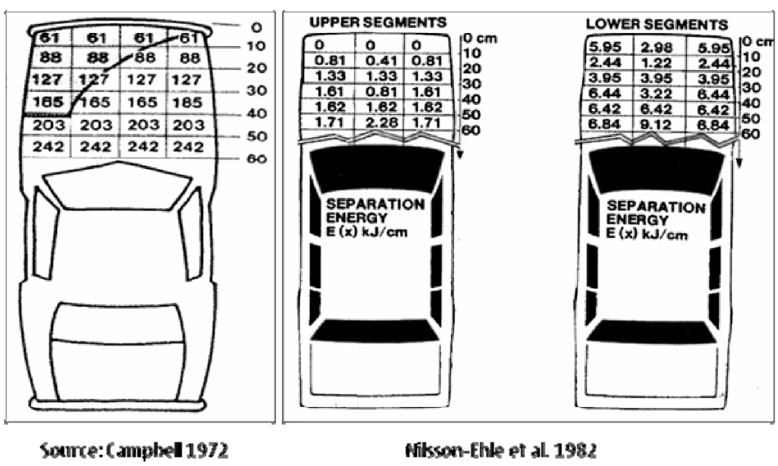

Fig. 8. - Energy matrixes

These methods produce a measurement of the violence of an accident, based on the energy which is absorbed by a vehicle during the crash phase. However, they provide limited information about the change in velocity (Δv) (Grime and Jones, 1969, Ventre, 1972, Prost-Dame, 1973). The ΔV of a vehicle can vary in different situations with e.g. the same BEV (Hight, 1985). But even when the ΔV is known, nothing indicates the manner in which the change in velocity takes place. How the occupant moves in the vehicle, and how the forces act during different phases of the impact, affect the injury outcome. Other measures have also been presented, e.g. mean acceleration (mγ) (Laboratory of Physiology and Biomechanics associated with Peugeot S.A./Renault, 1984).

Knowledge of the entire collision pulse, i.e. the time versus velocity/acceleration history, would, significantly enhance the quality of violence measures. Several types of crash recorders were presented during the 1970s and 1980s (Backaitis, S. 1977, Warner et al., 1974, Hudson, 1972, Sherwin and Kerr, 1979). Low cost crash recorders implemented in many vehicles were introduced in Sweden by Folksam Insurance Company (Aldman et al., 1991) and Volvo Cars during the early 1990s (Norin et al., 1994a).

Good knowledge about the type and severity of the exterior violence is essential for analysis of injury outcome. How the occupant strikes the interior structure of the occupant compartment depends on the conditions resulting from the exterior violence and various factors in the occupant compartment, i.e. the use of seatbelts, seating posture, occupant characteristics, etc.. The interior violence is mostly difficult to measure in traffic accidents.

The interior violence can cause different types of injury mechanisms for the vehicle occupants. An injury mechanism is the movement, or pressure/force, which occurs in, or in relation to, some part of the occupant body as a direct result of the interior violence. Different injury mechanisms cause different types of injury.

An important and necessary aspect of any analysis or evaluation of vehicle safety issues, is in-depth knowledge of the type and severity of the injuries incurred by the road users. The collection of injury data and the description and assessment of injury severity is therefore essential. There are a number of ways of describing and coding injuries. Most of them are based on the immediate outcome of an accident. Descriptive scales such as the International Classification of Diseases (ICD) and the measures of Activity of Daily Life (Yates et al., 1991), can be applied to any stage of the injury development process, such as immediately after the trauma or later. These scales do not predict anything; they only report the status of the patient at the chosen point in time of coding the injuries during the injury development process.

Predictive scales attempt to assess the future severity level for an injured person. These scales include the Abbreviated Injury Scale (AIS) which could be described as a threat to life scale (Committee on injury scaling of AMA ,1980), and is one of the most frequently used scales in road accident data, and other scales based on the AIS scale (Baker et al., 1974, Somers, 1983, Ulman et al., 1986). The AIS scale has been updated several times over the past years, with the latest version 2005. MAIS is often used to indicate the most severe injury on the body or a body part.

Long-term consequences of injuries cause much suffering and often high costs to the society. For a long period of time, different types of Injury Impairment Scale (IIS), Injury Disability Scales (IDS), and Functional Capacity Scales (FCS) have been under development. In the future, it is important to try to find scales with broad acceptance, which describes various important aspects of long-term problems.

SIMULATED LABORATORY ENVIRONMENT

During the development of new products, these have to be continuously evaluated to ensure that the desired effects of the products are achieved. The simulated environment must reflect the real environment as closely as possible, see Figure 9.

The way the simulated laboratory environment is made to represent the real traffic environment must be taken into account on several levels. On the scenario level, the driving/test scenarios set up, must mirror the accident/incident scenario it aims to represent as closely as possible. The type and level of impact severity on the vehicle level in real traffic must correspond with the simulated environment. At the occupant level, the virtual/physical dummies represent the various characteristics of the occupants. The way of measuring the dummy responses must also represent the different injury mechanisms and injury severities of the analyzed occupants.

Despite decades of biomechanical research, development of virtual and physical dummies and injury criteria remains a priority in the future to improve the quality of analysis.

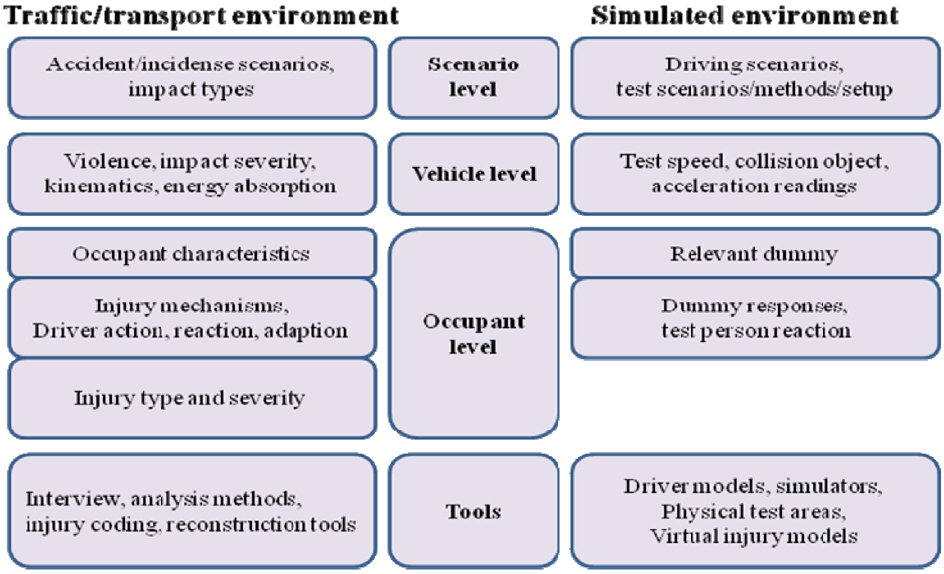

Fig. 9. - Relation real traffic and simulated environments

COMBINATION OF TRAFFIC ENVIRONMENT AND SIMULATED ENVIRONMENT

In the development process data from the traffic environment, the simulated environment and combinations thereof are used in different ways e.g. to evaluate the effect of systems in vehicles, aiming to reduce the risk of accidents and injuries to occur.

One example of estimating the effectiveness of measures taken to improve vehicle safety was described by Isaksson-Hellman and Norin (2005). Data was collected in Sweden between 1975 and 2004, and comes from crashes with Volvo cars manufactured between 1967 and 2005. Special consideration was given to a number of possible confounding factors, which could possibly influence the outcome of the analysis. With the possible influencing factors in consideration, the presented injury rate reduction was considered consistent. The overall injury rates MAIS2+, for 25,449 belted drivers in all crash situations grouped in periods of model year 1967-2005 are shown in Figure 10. The trend over the years is very positive; the injury rate is steadily decreasing with a total reduction of two-thirds from the earliest model years to the most recent.

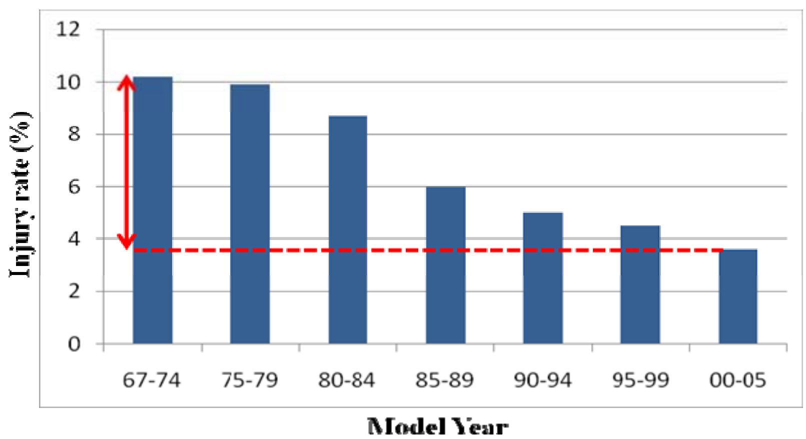

Fig. 10. - Estimation of injury rate reduction in cars of various model years

Correlation of accident data and laboratory data, where e.g. a relation between risk of injury and relevant dummy responses can be established, provide many opportunities in development work. Help to understand injury mechanisms, a base to formulate safety requirements and condition to be able to verify/evaluate the safety system during the development of vehicles, are just some examples of this. Methods which deal with these and similar relationships have been presented over a long period of time (Patrik et al., 1974, Lowne et al., 1976, Korner, 1989, Norin, 1994b).

A method for Evaluating Occupant Protection by Correlating Accident Data with Laboratory Test Data was presented by Korner (1989). This method has been actively used in product development. One important part of the procedure is the correlation between occupant injuries and dummy responses.

Korner states that: "Provided that the crash mode of the laboratory tests is equivalent to the real life accident type and that a valid crash severity parameter is used and that the protection criterion is a valid measure of injury production, then this correlation is generally applicable" (1989).

Based on accident data for a vehicle in production, the risk of injury as a function of impact severity is calculated for a given impact type and a given type of injury, see Figure 11 a and b.

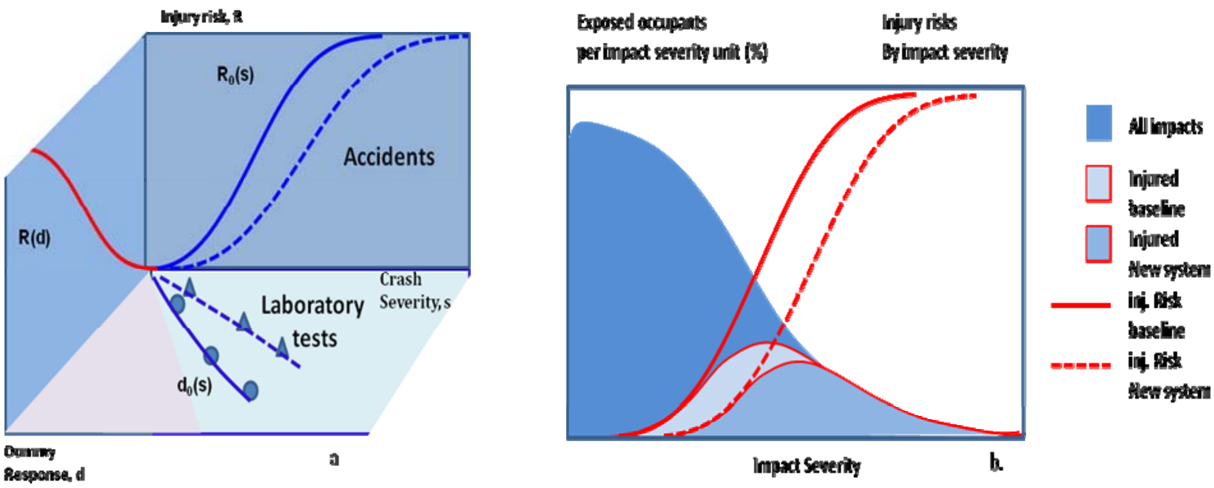

Fig. 11 - a. combination of injury risk and dummy response.
b. calculation of reduction in injury outcome.

The next step is to recreate a similar situation in the simulated laboratory environment. The injury risk function and the dummy response function is now combined to a relation between injury risk and dummy response, Figure 11 a. A modified vehicle/product is tested in the laboratory with the same condition as the base vehicle. With this data, and the previously estimated relation between injury risk and dummy response, it is now possible to calculate the injury risk as a function of impact severity for the modified product. With the injury risk functions for the base vehicle and the modified vehicle, and knowledge of the impact severity distribution for the selected population, it is possible to calculate the reduction in injury outcome, see Figure 11 b. This method has been developed and extended in various ways, e.g. by including occupant size (Norin, 1994b), and by combining the pre-crash phase and the crash phase, in what is called Volvo cars´ general Benefit Estimation model (Lindman and Tivesten, 2006). This method has also been used for evaluation of new active safety systems in cars, e.g. evaluation of Auto Brake Functionality in reduction of pedestrian fatalities (Lindman et al., 2010). Many other method developments and analyses to facilitate estimation of the benefit of different safety technologies have been presented, from field data only or combinations of field data, laboratory data (e.g. testing on test tracks), Field Operational Test (FOT) and driver simulators (e.g. Pack et al., 2006, Erbsmehl, 2009, Hannawald et al., 2008, Gordon et al. 2010, Najm et al., 2006, Ljung Aust et al., 2009).

SUMMARY AND DISCUSSION

To understand to what extent, and how accidents and injuries occur in the transport area, requires field data of high quality and quantity. Collection and analysis of field data has been ongoing for many decades. Awareness of the value of field data to make the right priorities, understand the underlying mechanisms of accidents and injuries, and to evaluate the new system, has gradually increased over the years and is today a natural part of the development process of safe vehicles.

During the 1950s and 1960s, field data was collected and analyzed by the car companies, universities, and authorities, with limited coordination between the parties. The difficulty of comparing different materials from different databases revealed the need for coordinating the definitions and methodologies. As early as the 1960s, activities to harmonize various aspects of field data, such as how to describe vehicle deformations, began (Nelson, 1980).

The researcher's level of knowledge of the area, and limited technology influenced how the data could be collected, stored, and analyzed. E.g. computer storage capacity and data analysis were very limited compared to the opportunities of today. This resulted in many challenges, but also influenced the creative work to create better conditions. Even in the laboratory environment, were limitations in experience and tools. The understanding of injury mechanisms and how these can be represented and reconstructed in the simulated environment has required extensive biomechanical research over the years. An important part of this work is also the development of methods to correlate the traffic and simulated environments.

Today, the conditions to efficiently use field data in the development work, are much improved since the period 1960-1980. Data capacity, technical equipment, and, not least, increased knowledge, improves the possibilities for high quality analyses. The need for a continued development of the methods and techniques to collect, store, and analyze data on accidents and injuries in traffic is still significant and must remain a priority in the future.

In recent years, various activities to collect naturalistic data from normal driving of vehicles have opened up opportunities to get an understanding of the underlying factors that cause accidents. Data from the vehicle, e.g. speed, steering, brakes, etc.; the driver, e.g. , eye tracking, video recordings; and the traffic environment e.g. video recordings, maps, road data, is stored continuously under normal traffic conditions for long periods of time. This provides very extensive data sets and very good possibilities for the future to understand the occurrence of accidents and incidents, and to evaluate the system developed to provide enhanced safety of vehicles. This type of data creates new requirements on how data is collected, stored and analyzed compared to traditional data from traffic accidents..

A better understanding of injury mechanisms and consequences of injuries continues to have a biomechanical research priority, as well as the development of methods and tools to simulate and evaluate system solutions in the laboratory. An important factor in assessing the consequences of injury is increased knowledge of the long-term consequences of injuries, and the development of methods for classifying them.

The future requires a continued collection and analysis of field data, both traditional accident data, and data from continuous driving of vehicles in normal traffic. An important step in the future is also to develop new methods that effectively combine traditional accident data, vehicle data from normal driving, and techniques for accident reconstruction.

Over the years, experiences have been built to use field data information to create safer vehicles. This article outlines some of the historical events and points out the importance of this process. This process has had an important role in reducing injuries and fatalities over the years, and will certainly make a difference in the future development of accident avoidance as well

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