INJURY POTENTIAL PREDICTION OF A SAFETY DESIGN FEATURE. A THEORETICAL METHOD BASED ON SIMULATIONS AND TRAFFIC ACCIDENT DATA.

HANS NORIN
Volvo Car Corporation, Gothenburg, Sweden

IRENE ISAKSSON-HELLMAN
Volvo Data AB, Gothenburg, Sweden

ABSTRACT

A safety design feature must be evaluated in several crash modes and taking into account the distribution of essential parameters. This report presents a method whereby the safety potential of a car or a safety design feature can be predicted before the car/system is exposed to real traffic conditions. This is done by combining data from crash tests or mathematical simulations with traffic accident data and by paying particular attention to the crash severity and occupant size parameters.

INTRODUCTION

In order to predict the safety potential of a safety design feature, laboratory/mathematical simulation data must be linked with traffic accident data in a reliable manner. The dummy responses measured in the crash tests and mathematical simulations must correlate well with the type/types of injury they represent, that is the biofidelity must be high.

Animals and cadavers have been used to determine injury mechanisms and to find correlations between injuries and dummy responses (Wall and Lowne, 1974; Tarrière, 1987; Viano et al., 1989; Roberts et al., 1990). Owing to the differences between animal/cadavers and live humans, there will naturally be uncertainties in these studies.

Standardized crash tests which have been used worldwide for many years to estimate the "safety level" are generally carried out at about 50 km/h (30 mph) or about 56 km/h (35 mph), using a 50 percentile "male" dummy as the occupant. The results at other crash speeds and using other dummy occupant sizes have rarely been considered.

If crash tests carried out with <u>one</u> dummy size and at <u>one</u> speed are used to estimate the safety potential of a car or a safety design feature, the reliability of the findings must come into question. (Norin et al., 1991). It is suggested, therefore, that a safety design feature should be evaluated in several crash modes with the distribution of essential parameters being taken into account. This leads to greater precision in the total assessment. A parameter of great importance is the crash severity.

When the term "crash severity" is used in this study, it represents any form of violence to which the occupant was subjected, whether injured or not. Many reports (Lowne and Wall, 1976; Mills et al., 1984; Horsch, 1987; Jones and Whitfield, 1988; Korner, 1989;) discuss the risk of sustaining a certain injury as a function of the crash severity.

The dummy response amplitudes for a given crash mode can be determined as a function of the crash severity. In this way a relation between the risk of injury and the relevant dummy responses can be obtained. With this relation, the risk of injury, as a function of crash severity, can be determined for a new design feature.

When the risk of injury is known, the total injury frequency of a certain design can be determined using the information about the crash severity distribution. Methods which deal with these or similar relations have been presented earlier (Lowne and Wall, 1976; Appel et al., 1979; Mills and Hobbs, 1984; Malliaris et al., 1985; Danner et al., 1985; Horsch, 1987; Korner, 1989; Kramer and Appel, 1990).

The size of the occupant is another essential parameter. Depending upon their size, occupants come into contact with different parts of the interior during a crash, and this will affect the risk of injury.

The purpose of this study was to develope a method for prediction of the safety potential of a car or a safety design feature before exposure to real traffic conditions. This was done by combining data from mathematical simulations with traffic accident data and by taking into account not only the crash severity but also the occupant-size parameter.

METHOD

The method combines data from a validated mathematical simulation model or from crash tests with traffic accident data, with particular attention paid to the crash severity and occupant-size parameters.

Analysis procedure

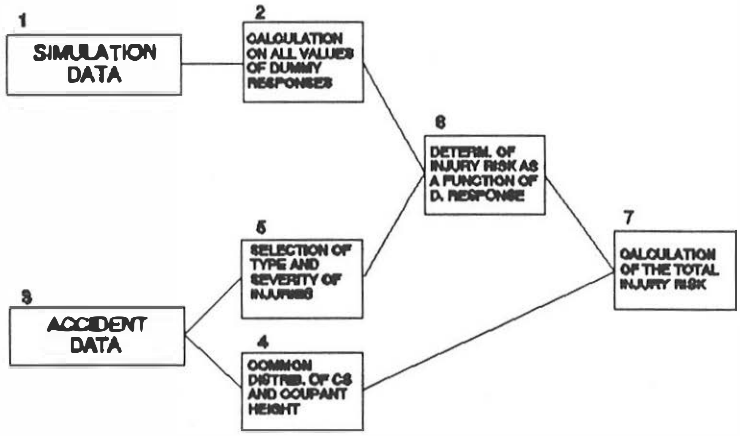


Fig. 1. Analysis procedure

From the simulation data {1}[1] we obtain dummy responses for the specific combinations of crash severity and dummy size,

---

[1] No in {} ref. to the boxes in Fig 1.

used in the simulation (see also Fig. 2).

From these dummy responses, all the values in between are calculated {2}, by interpolation and extrapolation, for all the defined combinations of crash severity and occupant size (see also Fig. 3).

From the accident data {3}, the distribution of crash severity and occupant size is obtained. The common distribution of these two parameters gives the proportion of occupants for each combination of crash severity and occupant size {4} (see also Fig. 6).

The relevant type and severity of injuries are selected to correlate with the dummy responses. Occupants with a chosen type of injury and a specific injury level are considered "injured", occupants injured below this level or uninjured occupants are considered "uninjured", {5}.

The relation between injury risk and dummy response can be calculated (from {2} and {5}) using logistic regression (Walker and Duncan, 1967), {6}, (see also Fig. 7).

Information from {6} - injury risk vs dummy response - and {4} common distribution of crash severity and occupant size - are combined to calculate the total injury frequency {7} (see also Table 1).

Different types of accidents and/or injuries can be analysed in a similar way, provided there is relevant accident material and accident types and injury mechanisms can be simulated in a laboratory or in a simulation model.

Belted drivers in frontal impacts are used in the following presentation of the method. Head injuries (AIS2+) (AIS, 1980) to the drivers are correlated with simulation parameters for Head Injury Criteria (HIC_{36}) (NHTSA, 1986). EBS (Equivalent Barrier Speed) is used as the crash severity parameter. EBS is calculated according to a method developed at Volvo (Nilsson-Ehle et al., 1982; Magnusson and Jörgensson, 1987). The size of the occupant is represented by the driver height.

Simulation data

In this report, MADYMO mathematical simulation models (TNO, 1990), are used. The MADYMO simulation models were validated for Volvo 240 cars from full scale crashes at several speeds and from a Hyge sled test series. The same car model was also used in the analysis of the accident material.

The mathematical simulations were carried out at various crash speeds (EBS) and three dummy sizes. In this example, the crash speeds were about 24 km/h, 40km/h, 56 km/h and 65 km/h (15 mph, 25 mph, 35 mph and 40 mph), and 5-, 50- and 95-percentile Hybrid III dummies were used.

In the model, the crash speed (EBS) ranges between 0 km/h and about 80 km/h (0 mph and 50 mph) and the driver height between 150 cm and 200 cm. Twelve HIC_{36} values were obtained from the simulations (Fig. 2). In the following, these results will be directly correlated with head injuries (AIS 2+) for belted drivers in frontal impact accidents.

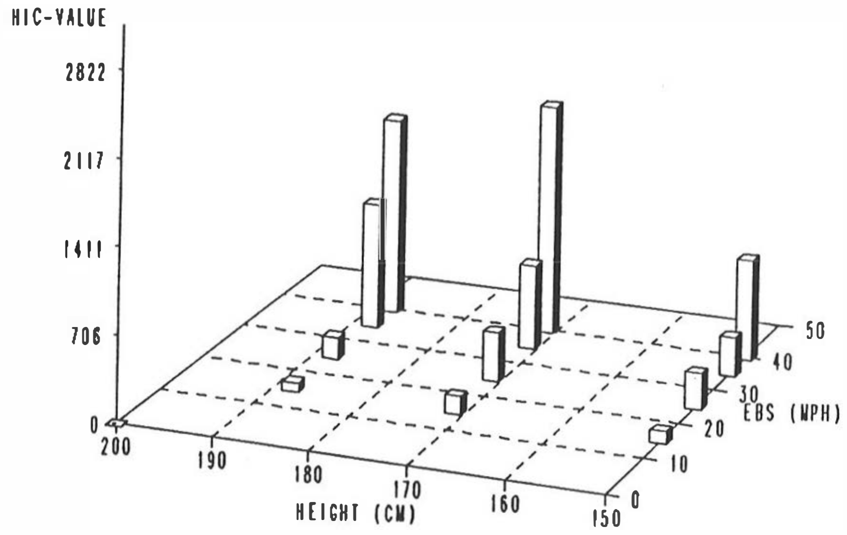


Fig. 2. HIC_{36} values obtained from the simulation.

With the simulation results (Fig. 2), HIC_{36} can now be calculated for all the combinations of driver height and EBS. This is done by interpolation between the known HIC_{36} values and by extrapolation of the HIC_{36} values to the limit of the defined area (150-200 cm driver-height and 0-50 mph EBS). The method is to adapt a surface which passes through the points and connects them (SAS/GRAPH, 1990). The resulting surface is illustrated in Fig. 3.

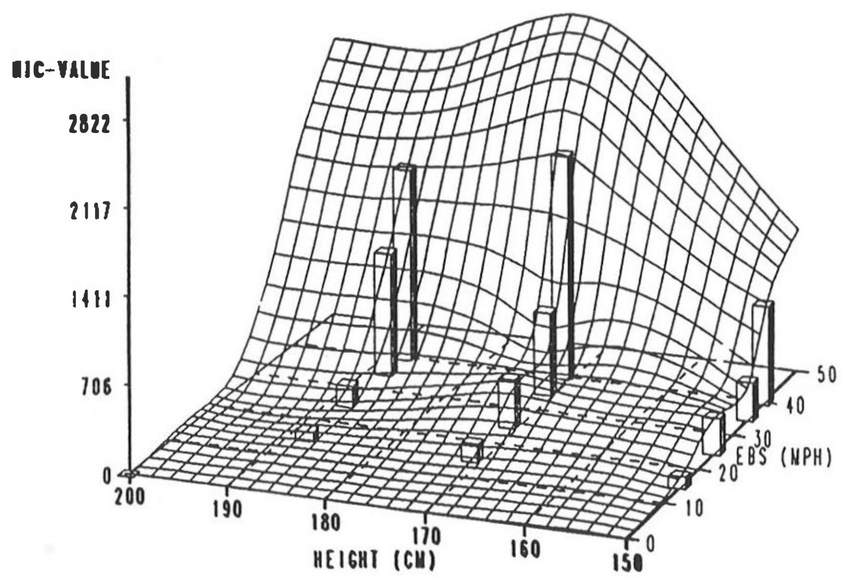


Fig. 3. The surface that describes the HIC_{36} values for all the combinations of EBS and driver-height.

Accident data

The accident material used in this example consist of 2547 "pure" frontal impacts using a Volvo 240 model. The analysis has been done for drivers using three-point seat belts. In this example, EBS and driver-height require closer study. Both these parameters have a noticeable effect on the movement pattern and points of impact in the interior during a frontal collision, and this naturally affects the kind of injury to the driver. The distribution of EBS, or generally f(cs), was obtained from the accident material (Fig 4).

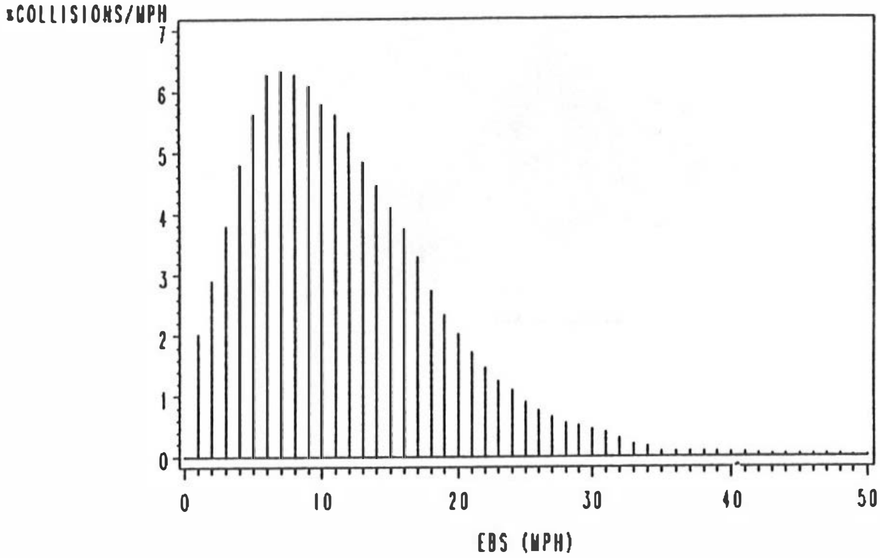


Fig.4. Distribution of EBS, (crash severity, f(cs)) in frontal collisions. (N=2547)

The other parameter is the driver's height. Sitting height may be more relevant but are often difficult to obtain when gathering accident data. The driver's height distribution f(h) is determined from Volvo's statistical accident material (Fig. 5).

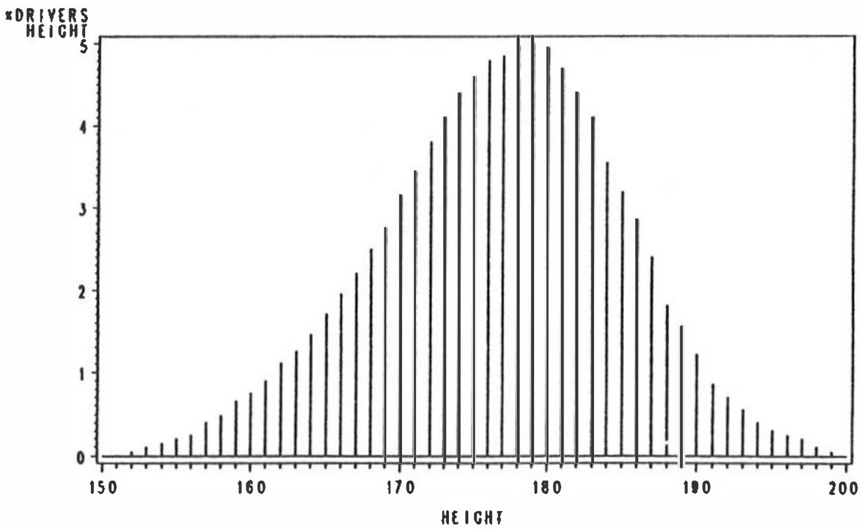


Fig. 5. Distribution of driver height f(h) (N=2547).

The two-dimensional distribution of EBS and driver-height f(cs,h) is calculated by multiplying the two separate distributions. Since EBS is measured for each mph between 1 mph and 50 mph, and driver-height for each cm between 150 cm and 200 cm, this will give a distribution of a total 50 * 51 = 2550 points. (Fig. 6)

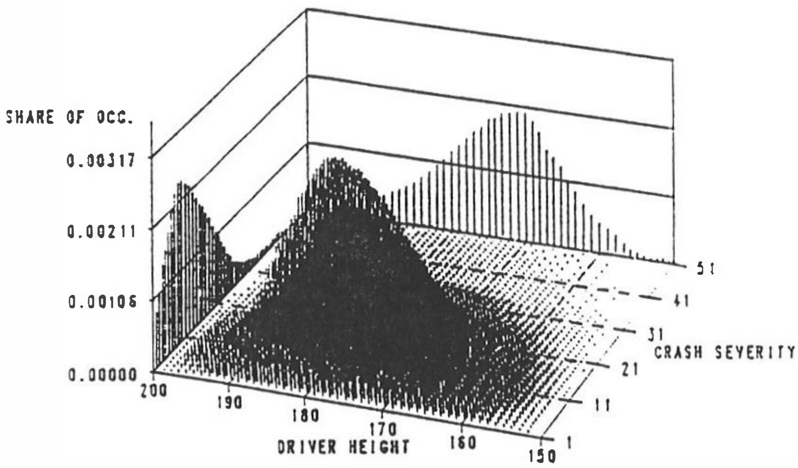


Fig. 6. The combination of EBS and driver-height distribution, f(cs,h).

The bar at each point of intersection in the diagram thus shows how often this combination of driver-height and EBS occurs in relation to all the possible combinations.

A HIC_{36} value is calculated for each combination of driver-height and EBS from the simulation result above. The share which each HIC_{36} value constitutes is received by adding the proportions with the same HIC_{36} value.

This can be expressed by $\sum_j X_{j,k}$, where

j = the intersection point of a specific EBS and a specific driver-height

k = a certain HIC_{36} value

$X_{j,k}$ = the proportion of HIC_{36} value (k) of intersection point j.

We thus have the following relation:

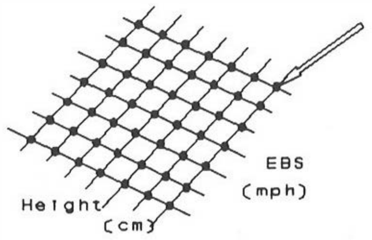
$$\sum_j X_{j,0} + \ldots + \sum_j X_{j,maxk} = 1$$

Determination of injury risk as a function of HIC_{36}.

The calculation of HIC_{36} is now combined with the drivers' head injuries (AIS 2+) for each combination of EBS and driver height.

Drivers with head injuries (AIS 2+) will now be considered as "injured" and the remaining occupants as "uninjured".

From each intersection point of EBS and driver height, we now have knowledge about:



* HIC_{36} value
* Proportion of drivers
* Number of injured/uninjured

This information is now used to set up the relation between HIC_{36} and injury risk. This is done by using logistic regression (Walker and Duncan, 1967) to fit a continous function, from the discrete points (uninjured=0, injured=1) for each HIC_{36} value, Fig. 7. The relation, which reflect the spread of tolerances in the chosen occupant population, will of course be different for different occupant populations, where factors as the age, sex, etc. will influence.

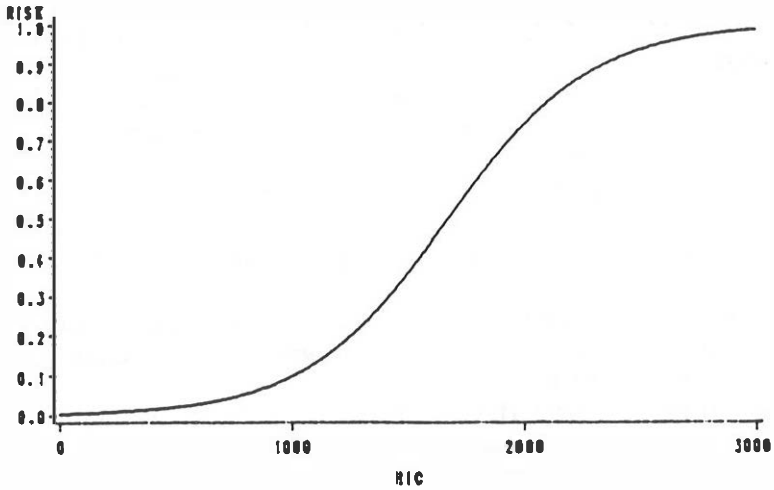


Fig. 7. The risk of injury as a function of the HIC_{36} value.

Such a correlation between injury risk and dummy respons is valid only under certain conditions. Korner (1989) has formulated: "Providing 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".

Calculation of the total injury frequency.

A risk of injury at each HIC_{36} level (k) has been assigned and also the proportion of each k. The total head injury frequency can be calculated with these values:

Table 1. Calculation of the total injury frequency for a given type of injury.

Proportion of total	Risk of injury per "k"	
$\Sigma X_{j,0}$ . . . $\Sigma X_{j,maxk}$	R_0 . . . R_{maxk}	$\Sigma X_{j,0} * R_0$ . . . $\Sigma X_{j,maxk} * R_{maxk}$
Total injury frequency (in this case head injury AIS 2+):		$\sum_{k=0}^{maxk} (\sum_j X_{j,k} * R_k)$

The total injury frequency for certain types of injury is calculated using this procedure (in this case, head injury, AIS 2+). Theoretically this calculated risk of injury should be the same as the head injury frequency calculated directly from the accident material because they both describe the same thing. The results of the calculations are standardized with regard to the injury frequency in the accident material so that they are both in agreement. To illuminate this, if the accident material has an injury frequency of 0.025 and the calculations give an injury frequency of 0.023, we take the ratio of 0.025/-0.023 and multiply with the calculated values.

DEMONSTRATION OF THE DESCRIBED METHOD

If the HIC_{36} values from Fig. 2 are used, and the described calculation procedure is followed, the total head injury frequency (AIS2+) will be 2.9 %.

The new design solution used in this example is to add a pretensioner as a modification to the basic seat belt concept.

The MADYMO model is changed by inserting the pre-tension characteristic. The new design can now be simulated at the same EBS levels as before and with the same dummy sizes. The result of this simulation is presented in Fig. 8.

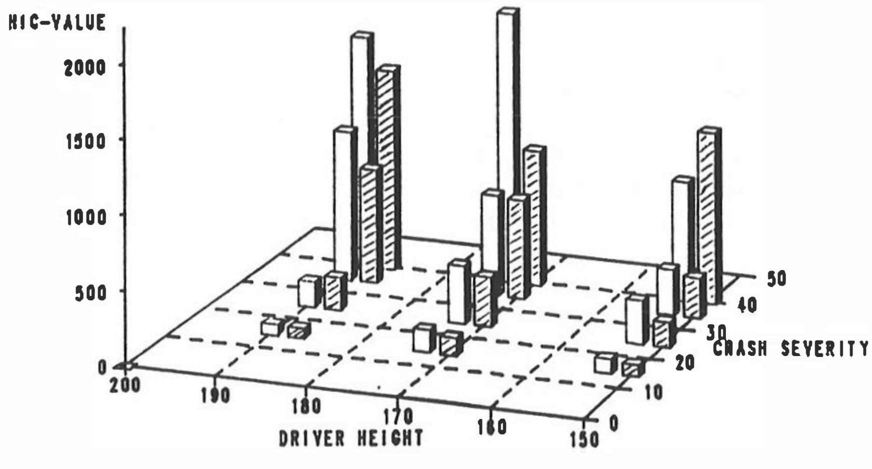


Fig. 8. Simulated HIC_{36} values for the basic concept and the car with pretensioner.

The test is run in the same way as for the baseline car. Thus the same distributions of EBS and driver-height are used (Fig. 6).

The new injury risk for each combination of EBS and driver height is determined by using the previously calculated relation between head injury risk and HIC_{36} (Fig. 7) and the new simulation results (Fig. 8). The new total head injury risk can thus be calculated. In this example, the new head injury risk is 2.6 %. This will give a reduction of head injuries (AIS 2+) to the driver of about 10 %.

DISCUSSION

The purpose of this method is to create a means of predicting to what extent a new system/component for a car can influence the risk of injury.

There are a number of parameters, e.g. crash severity, occupant size, seating position etc., which influence the risk of injury. Information on the distribution of these parameters can increase the accuracy of the assessment.

Crash severity is a very important parameter. In the method presented, EBS (Equivalent Barrier Speed) was chosen for front-end collisions in traffic accidents. EBS is the speed at which a vehicle must hit a barrier in order to absorb the same amount of energy as that absorbed by a corresponding vehicle's deformation in a traffic accident. Another measure of the crash severity is the velocity change of the occupant compartment, which can be estimated if the characteristics of the crash object are known (e.g. the other vehicle's weight). Furthermore, the retardation phase provides other parameters e.g. pulse shape, mean acceleration (Thomas et al., 1989) which probably affect the results. However, the various forms of crash severity which can be used in the analysis will not be discussed further in this report. It is sufficient to point out that this is an important parameter which merits further study.

In front-end collisions with the same primary violence (here EBS), the occupant will hit the interior (steering wheel, dashboard, etc.) at different places and at different contact speeds. If the contact speed between the occupant and the interior could be estimated, one would obtain a new measure of violence, which, in certain cases, probably correlates better with the injury outcome than the primary violence.

The contact speed is also influenced by the occupant movement, which is dependent on parameters such as occupant size and weight, occupant mobility (stiffness of joints, etc), muscle activity, sitting posture, seat properties (stiffness, upholstery, etc.), type of restraint.

A determining factor for the analysis is the connection between occupant injury and the measuring value which is to represent the injury. Before we make this connection, we must clarify the injury mechanisms for the injuries in question.

As an example, two different measurements of chest injuries can be compared. How different properties affect these can be studied. A driver wearing a seat belt is retarded by the belt in a front end collision. In this case, there is retardation of the chest and internal organs as well as compression of the rib cage caused by the pressure of the seat belt. If the driver is able to offer any resistance by pressing his arms against the steering wheel during the course of the collision, retardation of the chest would naturally increase because of the increase in counteracting forces. At the same time, the belt force and compression of the rib cage would decrease owing to the supporting pressure of the arms against the steering wheel.

With counteracting forces such as those above, acceleration of the chest increases, while chest deflection is reduced. What is the cause of chest injuries then? Both mechanisms probably influence the result, although to different degrees, depending upon the type of injury involved. Some parts of the chest are affected more by acceleration and others more by deflection.

Quite clearly, it is of the utmost importance to clarify the injury mechanisms, as far as possible, for different types of injuries, and to try to find the measuring values which correlate best with the injuries. Here it is important to know that the tolerance level varies from occupant to occupant.

Apart from the uncertainty of the connection between the parameters in the accident analysis and the simulation (e.g. crash severity, harm/dummy measuring value) there are certain comments to be made regarding the different stages of calculation in the procedure.

The distributions of crash severity and occupant size are combined as a two-dimentional distribution. This must be done on the supposition that the two parameters are independent. With the two parameters, crash severity and occupant size, it is quite possible, however, that this is not true. Shorter drivers for example (often women) may have a different crash severity distribution to taller drivers (often men). In the accident material used in this analysis, it is not possible, however, to show any significant difference in crash severity distribution between short and tall drivers.

If there is a difference in the accident material, it is perhaps better to calculate the actual proportion for each combination of crash severity and occupant size directly on the basis of the accident material.

Twelve simulated measurement values are given when adapting the surface which is to relate a measurement value to each combination of occupant height and crash severity. There is, of course, some inaccuracy when an approximate surface area is created with the help of these 12 points, to receive a measurement value for each combination (2,550 points). Assessment of this inaccuracy shows, however, that it has only a marginal effect on the results, less than 2 %.

When the connection between measurement value, occupant height and crash severity is clear, it is used to calculate a risk curve, as a function of the measurement value, from real accident data.

This is done with logistic regression, which is a suitable model for this type of data (injured/not injured), (Strother H. et al., 1967). A procedure for this calculation is laid out in SAS. The appearance of the risk function is dependent upon the variance. The procedure shows this, as well as how relevant the model is. Finally, the risk function is multiplied by the proportion of each measurement value.

Theoretically, the result should agree with the relative injury frequency of the injury in the accident material.

However, the values may vary slightly depending upon variations in the calculation. In the tests which were performed, the variation has been less than 5 percent.

The method can be generalized for other protection systems and for other accident types. The conditions require, however, a relevant crash severity measure and a laboratory measurment value which correlate well with the injuries.

REFERENCES

Appel H.; Kramer F.; Hofman J. - Protection criteria for occupants and pedestrians. - Proceedings of the 7th ESV Conference, Paris, 1979.

AIS; Committee on Injury Scaling of the American Medical Association, American Association for Automotive Medicine and the Society of Automotive Engineers. The Abbreviated Injury scale (1980 Revision). AAAM, Morton Grove, Illinois (USA), 1980.

Danner M.; Langwieder K.; Schmelzing W. - Aspects in optimizing car structures and passenger protection by a comprehensive analysis of car-to-car and car-to-object collision. - SAE Technical report No 850514, 1985.

Horsch J.D. - Evaluation of occupant protection from responses measured in laboratory tests. - SAE Technical report No 870222, 1987.

Jones I.S.; Whitfield R.A. - Predicting injury risk with "New Car Assessment Program". - Accident Analysis and Prevention, 1988.

Korner J. - A method for evaluating occupant protection by correlating accident data with laboratory test data. - SAE Technical report No 90747, 1989.

Kramer F.; Appel H. - Evaluation of protection criteria on the basis of statistical biomechanics. - Proceedings of 1990 International Conference on the Biomechanics of impacts, sept 12-14, Bron, France.

Lowne R.W.; Wall J.G. - A Procedure for estimating injury tolerance levels for car occupants. - Proceedings of the 20th Stapp Car Crash Conference, 1976.

TNO Road-Vehicle Research Institute; "MADYMO Users Manual 3D", version 4.3, The Netherlands, 1990.

TNO Road-Vehicle Research Institute; "MADYMO, Databases, Version 4.3, the Netherlands, 1990.

Magnusson Lennart; Jörgensson Mathias - Violence in frontal impacts. - Master's thesis, Chalmers/Volvo, 1987.

Malliaris A.C.; Hitchcock R.; Hansen M. - Harm causation and ranking in car crashes. - SAE Technical report No 850090, 1985.

Mills P.J.; Hobbs C.A. - The probability of injury to car occupants in frontal and side impacts. - Proceeding of 28th Stapp Car Crash Conference, 1984.

NHTSA, Department of Transportation, 49 CFR Parts 571, [Docket No. 74-14; Notice 47], Final rule, 1986.

Nilsson-Ehle Anna; Norin Hans; Gustafsson Christer - Evaluation of a method for determining the velocity change in traffic accidents. - 9th ESV Conference, Kyoto, 1982.

Norin Hans; Jernström Clas; Koch Magnus; Ryrberg Stephan; Svensson Sven-Erik - Avoiding Sub-optimized Occupant Safety by Multiple Speed Impact Testing - 13th ESV Conference, Paris, 1991, (Paper No. 91-S9-O-89).

Roberts A.K.; Janssen E. G.; Cesari D. - Review of cadaver responses to lateral impact and derived biofidelity targets for dummies. - Proceedings of 1990 International Conference on the Biomechanics of impacts, sept 12-14, Bron, France.

SAS/GRAPH Softeware; Reference, Version 6, First Edition, Volume 2, 664 pp, Cary, NC: SAS Institute Inc., 1990.

Searle J.A.; Bethell J.; Baggaley G. - The variation of human tolerance to impact and its effect on the design and testing of automotive impact performance. - Proceedings of the 22nd Stapp Car Crash Conference, SAE 780885, 1978.

Tarrière C. - Relationship between experimental measuring techniques, and real world injuries. - Symposium report, "Head Injury Mechanisms", AAAM, New Orleans, Louisiana, USA, 1987.

Thomas C.; Koltchakian S.; Tarriere C. - Inadequacy of 0 degree barrier with frontal real-world accidents. - 12th ESV Conference, Gothenburg, 1989, (Paper No. 89-2A-O-002).

Viano D.C.; Lau I.V.; Asbury C.; King A.I.; Begeman P. - Biomechanics of the human chest, abdomen, and pelvis in lateral impact. - Accident Analysis and Prevention. Vol. 21, No. 6, pp. 553-574, 1989.

Walker Strother H; Duncan David B. - Estimation of the pro bability of an event as a function of several independent variables. - Presented in Biometrika, 1967.

Wall J.G.; Lowne R.W. - Human injury tolerance level determina tion from accident data using the OPAT dummy. - Proceeding of the 5th ESV Conference, 1974.