ESTIMATION OF FRONT UNDERRUN PROTECTOR EFFECTIVENESS IN TERMS OF FATALITIY REDUCTION

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Paper Number 15-0041

ABSTRACT

Frontal collisions between cars and trucks lead to high fatality rate of the car driver. Therefore the Japanese road administration established a directive, conformity to ECE-R.93 (2000/40/EC), compulsory since September 1st, 2011. As known, this directive describes a ‘rigid’ Front Underrun Protection (FUP) device installed on a truck. New developments are in the direction of energy absorbing devices in order to manage more severe impacts between both vehicles. The question is how to estimate the effectiveness of these devices.

Using a virtual car fleet, the effect of different FUP devices installed on or integrated with a truck front end can be estimated by simulation, in terms of injury severity and crash severity. The relationship between both makes it possible to estimate injury severity via crash severity. By transferring injury severity to AIS scale and fatality rate, a coupling can be made with real accidents and their effects on injuries. The other subject is to indicate the car severity by replacing a specific car fleet to a general device, in order to simplify the evaluation. The paper shows the steps from the simulations, to the analyses and simplifications, transfer to AIS scale and mapping on the real accident database, to predict the reduction of fatalities by using different types of energy absorbing FUPs (e.a.FUP).

In order to represent the car fleet, the Moving Progressive Deformable Barrier (MPDB) was selected. The MPDB was modelled to collide to a truck with an e.a.FUP. By this method, number of fatalities, or fatality reduction rate of the car for a certain e.a.FUP was estimated from the MPDB crash severity.

The processes in this study are based on simulations and accident investigation and analysis. The vehicle models used in the simulations are mainly validated on NCAP frontal impact tests. Some cars were validated at higher speeds, up to 90 km/h.

In this paper the prediction of injury levels is only based on the HIC to show the concept/principle of the method, but the method can be extended with other injury parameters.

The method described in this paper uses the Acceleration Severity Index (ASI) of a car-to-truck frontal collision in order to determine the probability of injury and fatalities. It uses AIS scaling and mapping on a matrix of relevant car to truck accidents. This simplified method can be applied to predict the e.a.FUP effectiveness in terms of injury reduction, and especially the fatality reduction.

INTRODUCTION AND METHODOLOGY

New designs of safety structures need intensive testing and assessment before being realized and installed on vehicles on the road. However, the development of a realistic test setup is often a problem. Another problem is to find a way to value the usefulness and impact of the design on the society. In a previous paper [1] ways to test these structures, i.e. energy absorbing truck front underrun protection devices, were indicated. It was also suggested to use a generic test device instead of passenger cars with dummies for the final evaluation and assessment of newly designed truck front structures, and in particular an energy absorbing front underrun device. Using crash severity and accident severity information, the effect of a new design truck front structure can be estimated in terms of fatality reduction (See Figure 1).

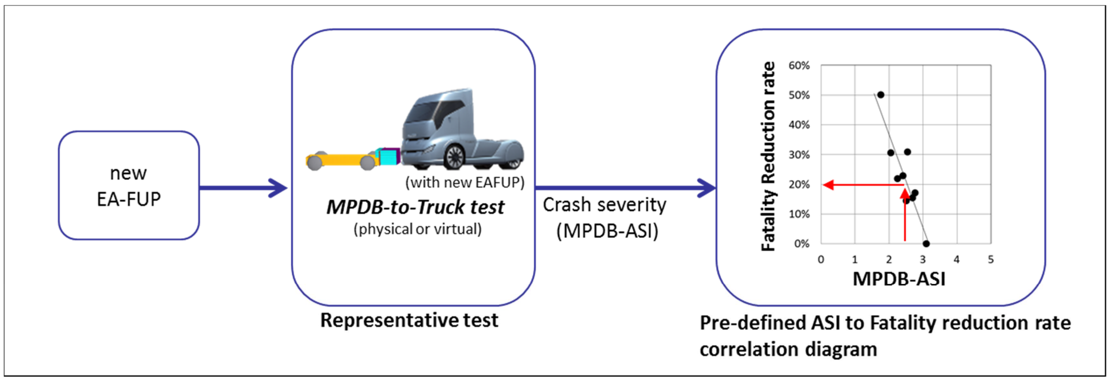

Figure 1. General concept of estimating FUP effectiveness

A similar idea but slightly different in implementation is given in [12]. The first steps to realize the above concept were made in [1]. In brief it boils down to the following. Based on accident investigation, vehicle registration and available test data a car fleet was selected and modelled. Also a 'standard set of FUP devices was defined, consisting of one 'rigid'FUP (fulfilling legal requirements) and 2 sets of 4 energy absorbing FUPs. Simulations of car-to-truck frontal collisions were carried out taking into account various accident parameters like relative speed and offset. This resulted in information about crash severity and injury severity. It appeared that a correlation can be indicated between the ASI and several injury parameters, like Head3msG, HIC, Thorax3msG, Chest deflection and Pelvis3msG. It also appeared that injury limit values for these injury parameters (e.g. HIC 1000) show an ASI limit value of 3 on an exponential curve. This process is visualized in the blue box, Figure 2-I.

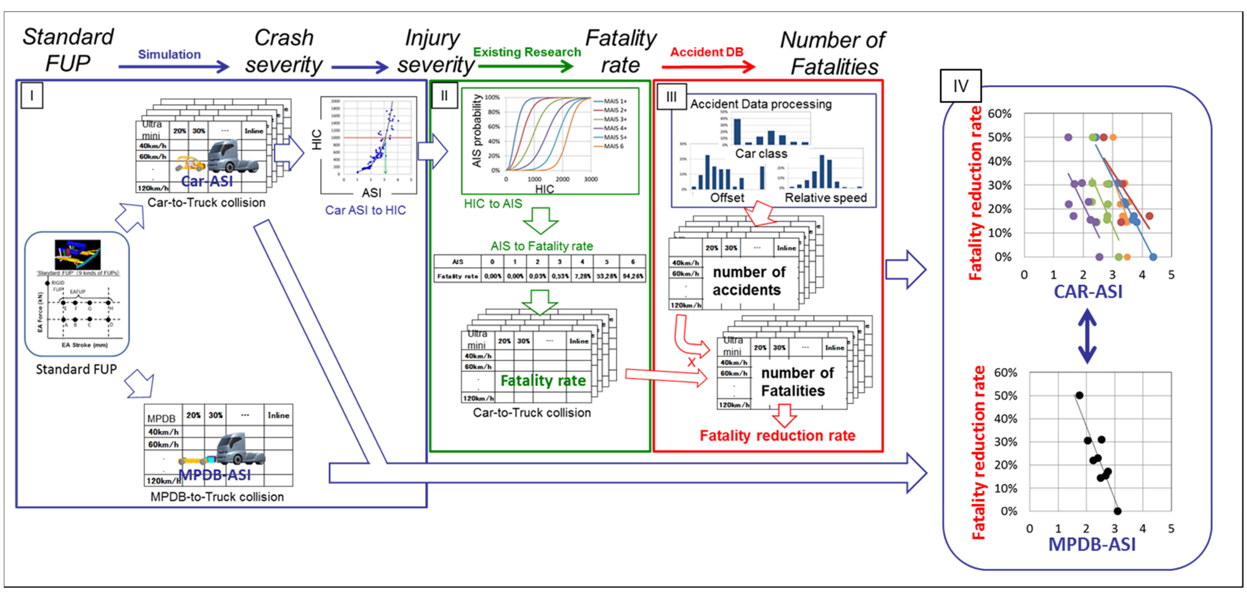

Figure 2: Outline of the method

The green box (Figure 2-II) shows how injury severity is transferred to Abbreviated Injury and subsequently to a Fatality Rate, which allows to transform the individual simulation data (Figure 2-I, blue box) to individual fatality data (Figure 2-II, green box). The next step is to associate this information with the information from accident data and fatality numbers (Figure 2-III, red box), resulting in a relationship between accident severity (CAR-ASI) and fatality numbers / fatality reduction rate (Figure 2-IV). In another line (bottom of Figure 2-I) the same batch of simulations is applied using a generic test device (MPDB) leading to a similar relationship between accident severity (MPDB-ASI) and the same fatality numbers / fatality reduction rate (Figure 2-IV). The relationship between CAR-ASI and MPDB-ASI will be shown in this paper, as well as the description of the consecutive steps mentioned above, starting with the green box.

HIC TO FATALITY RATE

For the quantification of occupant head injury (HIC), the Abbreviated Injury Scale (AIS) is used. Formulas for the HIC versus injury probability for the 6 AIS+ levels are given in [5]. In a similar way as described in [3], the correlation between HIC and AIS can be developed (See Figure 3). Combining this figure with the AIS 6 (fatal) curve, the probability of fatality can be determined (See Figure 2-II and Table 1). The probability of fatality is used to transform all injury data from the simulations to a fatality rate for the individual simulated accident cases (See Figure 2-II, bottom picture in green box).

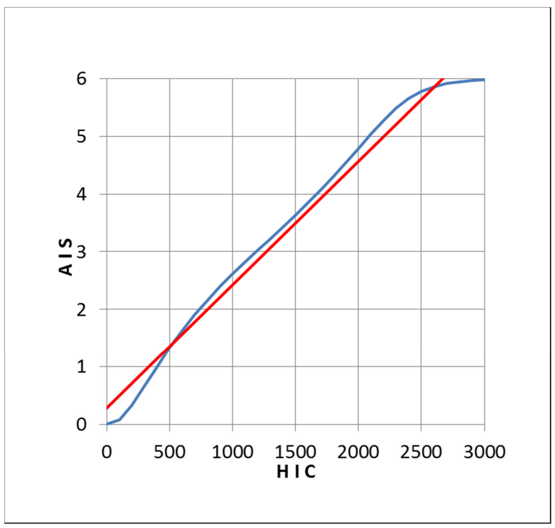

Figure 3: HIC-AIS relationship (trendline red)

Table 1. Relationship between AIS, HIC and fatality rate

AIS	0	1	2	3	4	5	6
HIC	0	329	798	1267	1736	2206	2675
HIC range	~ 93	94 ~ 562	563 ~ 1031	1032 ~ 1501	1502 ~ 1970	1971 ~ 2439	2440 ~
Fatality rate	0,00%	0,00%	0,03%	0,53%	7,28%	53,28%	94,26%

STATISTICS

The road vehicle registration database provides information about the amount of vehicles in different classes on the road. The traffic accident database provides information about the vehicle types involved in accidents and global information about collision type and injury. From in-depth accident analysis, more specific information on type of accident, speed and injury are known and can be rated in more detail.

Car distribution in car-to-truck head-on accidents

From the national accident database (2007 – 2011) [8] the representation of vehicles involved in car-to-truck head-on accidents can be obtained. As a standard for this database, the following classes have been defined: Ultra mini passenger car, ultra mini non passenger car, Sedan 1, Sedan 2, Mini vans, 1 box vehicles, SUV. In Figure 2-III the distribution of the cars in the different classes is shown. In the current study, however, another class definition was adopted: Ultra mini, Super mini, Small family, Saloon, SUV. This definition is more or less based on the one used by Euro NCAP. These vehicles represent 77% of the total registered cars. The numbers of vehicles in the 5 classes has been extrapolated to sum up to 100%.

Truck data

In the national accident database [8] most of the trucks were not supplied with a FUP (compulsory from September 2011 on new trucks). In the current paper it is assumed that trucks are fitted at least with a rigid FUP for determining the fatalities in these accidents. Therefore corrections were made on the number of fatalities, based on a study described in [4].

Relative speed

In the national accident database the traveling speeds of car and truck in the accidents is available. The relative or closing speed, however, is always lower than the sum of both speeds (braking). In this paper the relative speed is determined on the basis of an internal study by ISUZU. The distribution of the relative speed is shown in Figure 2-III. The relative speed concentration is around 80-100 km/h.

Offset distribution

From in-depth studies of special cases in the national accident database the offset distribution is estimated (See Figure 2-III). Especially in the high offset range this estimation is not always very precise. Offsets between 60% and inline can be everywhere in this range. Offsets collisions lower than 30% may result in a different event: the vehicle slides off instead of crashes into the truck front. Together with the offset limitation caused by the PDB width, the offsets in this paper range from 30% to 60%.

NUMBER OF FATALITIES AND FATALITY RATE

From the national accident database a total number of 433 fatalities in car-to-truck head-on collisions in the period 2007 – 2011 could be subtracted. From this number of 433, 53 cases were selected for in-depth analysis. The analysis resulted in allocation of these fatalities in the above mentioned categories of vehicle class, relative speed and offset. With this classification, including all 433 fatalities, and using the fatality rate with AIS score, a number of fatalities could be associated with each type of collision. This resulted in the graph of Figure 4. Taking the number of fatalities using a rigid FUP as the standard, a fatality reduction rate can be determined along the vertical axis of this graph, ranging from 0% (FUP performance identical to rigid FUP) to ~60% (FUP performance better than rigid FUP).

It should be noted that the trendlines for the 5 selected vehicles almost have similar slopes. This means that it does not matter which trendline is used to determine the amount of reduction.

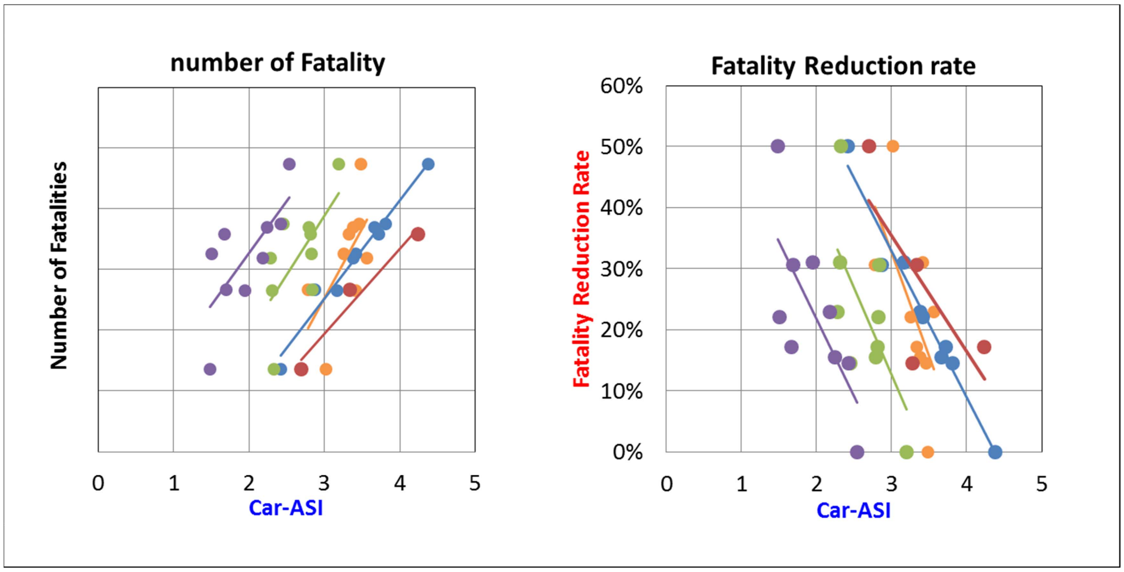

Figure 4: Car-ASI versus Number of Fatalities and versus Fatality Reduction Rate for the vehicle fleet

MOVING PROGRESSIVE DEFORMABLE BARRIER

The assessment of an energy absorbing front underrun protection device in terms of fatality reduction can be done by using a passenger car with dummies in a car-to-truck frontal collision. Instead, a Moving Progressive Deformable Barrier (MPDB) will be used for simplicity reasons, cost reduction and generalization. The MPDB was investigated within the FIMCAR project [11] in frontal offset car-to-MPDB collisions with the purpose of assessing self-protection and partner protection of passenger cars. Focusing on partner protection, the MPDB may be used in frontal offset MPDB-to-truck tests. The MPDB is then used as a loading device, replacing the impacting passenger car. Based on the results, a statement can be given on crash severity, injuries to passengers and the compatibility of the e.a.FUP and the passenger car's front structure.

New PDB

The geometrical conformity between a MPDB (Progressive Deformable Barrier installed on a trolley) and a passenger car and between a MPDB and a truck is shown in Figures 5a and 5b.

Figure 5a: Car front versus MPDB

Figure 5b: Truck front versus MPDB

The size of the PDB [10] (especially the height) is hardly of influence on the outcome of the test with the passenger car. However, in a test with a truck the upper part of the PDB may contact the stiff longitudinal members, tilt mechanism or cabin floor. This will not happen in a car-to-truck collision, or at least at a much later stage. The current size of PDB may lead to incomplete contact between the PDB lower part and the e.a.FUP. Therefore the conditions of a resized PDB have been evaluated, in such a way that they do not affect the current stiffness properties of the PDB.

The misalignments of the PDB have also been recognized in other research [6]. In relation with a truck front end, a number of modifications are suggested. The current height of the (M)PDB (700mm + 150mm ground clearance) might not be realistic for interaction with trucks. In [6] suggestions for adjustments and tests are made, see Figure 6a.

From studies by GRSP ECE-TRANS-WP29-GRSP-2007-17e and VC-COMPAT [9], this barrier front face includes nearly all stiff structural components of a selection of passenger cars. The depth of the barrier, especially with the stiff 90mm honeycomb at the back, is adequate for impacts with passenger cars, due to the load spreading capability in the car front structure. When impacting a truck front structure with mainly a FUP beam, this may lead to bottoming out of the barrier. Therefore the bumper structure from the Offset Deformable Barrier (ODB) was used on the PDB (See Figure 6b) to spread the local load from a single FUP beam into the PDB.

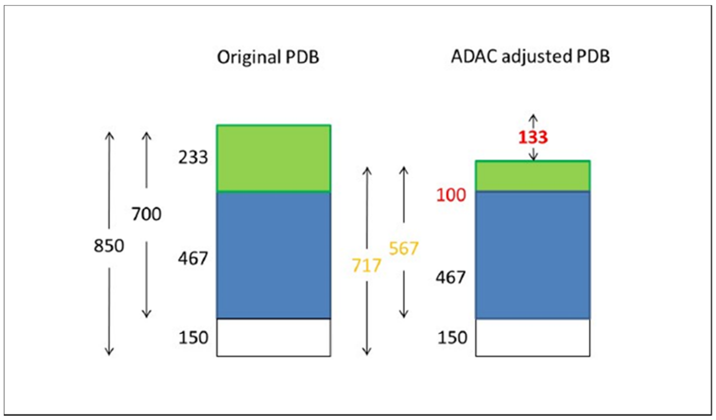

Figure 6a: Original and alternative front of PDB

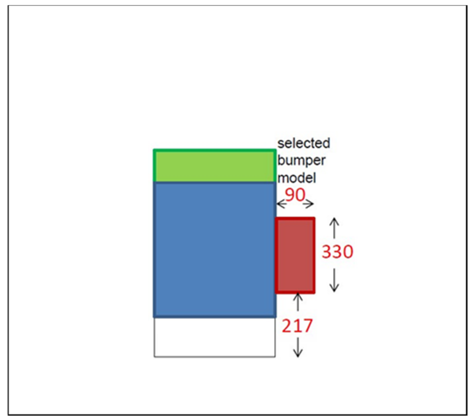

Figure 6b: Alternative PDB front with bumper

It is clear that the bumper structure does not allow aggressiveness assessment according to the standard PDB protocol. However, the modified PDB reflects better the load spreading by an average passenger car.

Regarding the width of the PDB, the MPDB-to-truck collision with the current barrier width of 1m limits the overlap of the car by approx. 60%. (see Figure 7). So higher overlaps and in-line collisions can not be tested in this way.

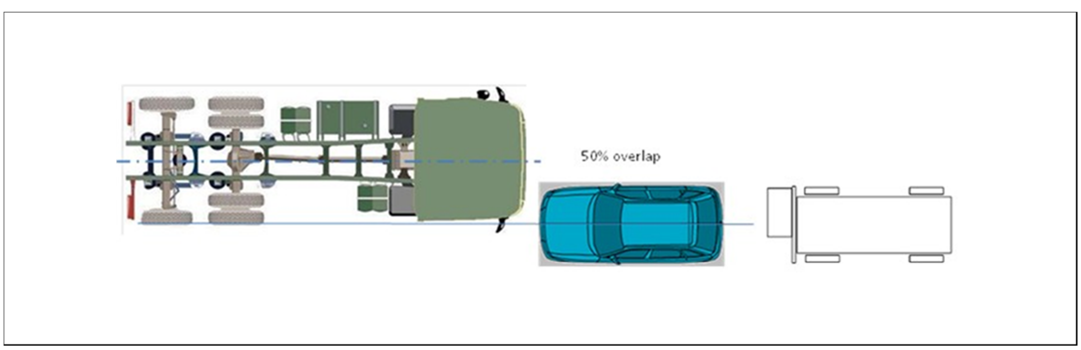

Figure 7: Overlap of passenger car and MPDB

MPDB simulations and ASI comparison

Using the modified PDB, a batch of simulations was carried out. The parameters relative speed, offset and FUP type were varied. The results of these simulations produced an accident severity value ASI for each case. Combining these MPDB-ASI values with the CAR-ASI values obtained from the batch of car simulations, the graphs of Figure 8 can be composed. It appears that a linear relationship can be indicated between car and MPDB ASI.

A linear relationship allows a transformation from the Fatality Reduction vs CAR-ASI graph to the same graph with the MPDB-ASI on the horizontal axis.

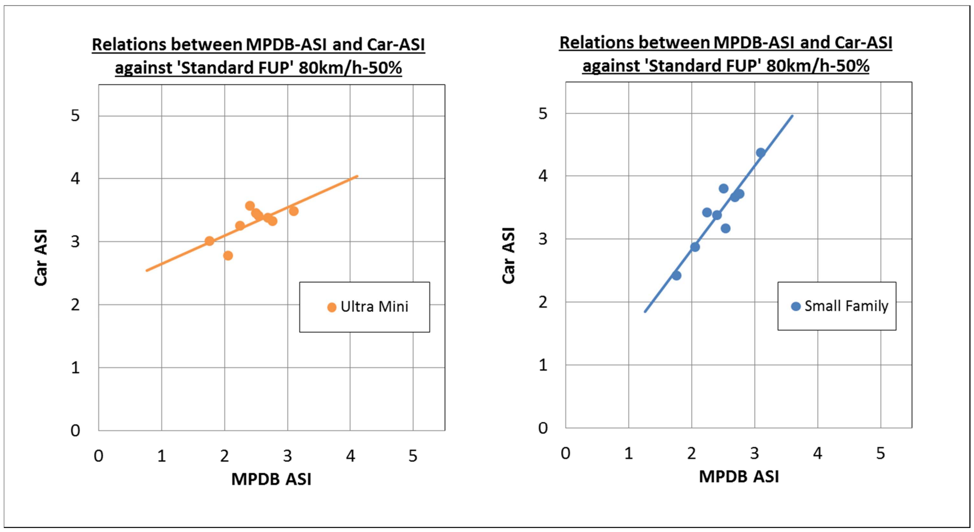

Figure 8: Relationship between CAR-ASI and MPDB-ASI

SELECTION OF TYPICAL ACCIDENT

In order to estimate the effectiveness of a new FUP design, in terms of fatality reduction, relative to a legal rigid FUP, many simulations can be carried out and studied. These include ranges of relative speeds and offsets. From the accident investigations it appears that most accidents and fatalities occur in a speed range of 80-100 km/h. Collisions with relative speeds up to 90 km/h show that damage to the vehicles is large and that the energy absorbing capabilities of the vehicles are fairly to fully utilized. The offset concentration is around 40-50%. Close to 30% may lead to different impact behavior. Therefore a typical accident is chosen with relative speed of 80 km/h and 50% offset.

EVALUATION NEW FUP DESIGN

The introduction of a rigid FUP on new trucks by enforcement through rule making is a very good step to reduce the seriousness of car-to-truck frontal collisions. Many studies, however, have shown that energy absorption by the truck front end is a good way of reducing the seriousness even further. By applying the method developed in this study the reduction can be quantified. A simulation of a collision (80 km/h, 50% offset) between the MPDB and the truck supplied with the new front structure results in an ASI value indication the severity of the crash. In Figure this value is put on the horizontal axis. When being left of the intersection of the trendline with the horizontal axis, the new front structure has a benefit on the fatality reduction. The reduction rate is determined by vertical intersection with the trendline. An ASI value of 2.5 for instance results in a reduction rate of 20% with respect to a rigid front underrun protection device.

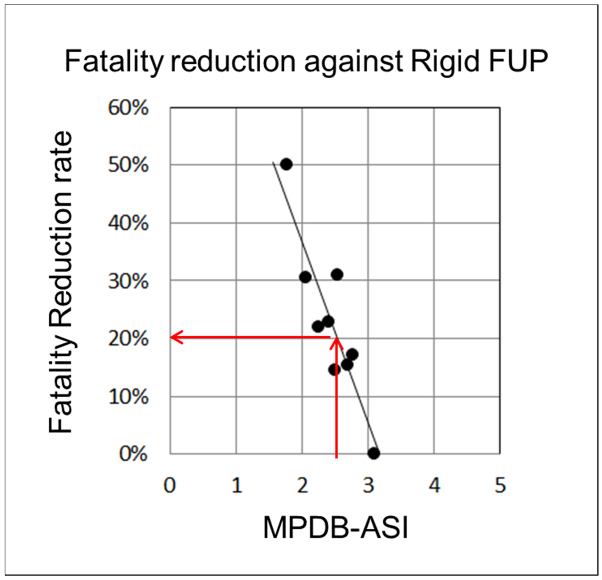

Figure 9: Determination of FUP effectiveness in terms of fatality reduction rate.

DISCUSSION

There are a number of limitations to the study. The selection of car models which are defined as representative for the classes in the fleet is based on the availability of crash test results (from NCAP tests or private tests). Except for the in-house tests, which are carried out at high speeds, up to 90 km/h), the NCAP tests are normally carried out at speeds from 56 km/h to 64 km/h. In case overload situations (high speed impacts, up to 90 km/h) are simulated, the results may be different for models which have been validated against lower speed impacts. Therefore, the simulations outside the validation range are handled with care.

The width of the PDB is limited to 1000mm. As a consequence, only overlaps up to 60% be realized. Small overlaps are limited to approx. 30%. The PDB is uniform over the barrier width and smaller overlaps typically result in a different collision phenomenon. The MPDB is not representative for all type of cars.

Each simulation results in a set of injury values (head, chest, pelvis, etc.) for the occupant in the passenger car. In the study above only the HIC value is used to determine fatality via AIS. Other injury values can be involved in a similar way. However, AIS is a measure in accident investigation that describes the injury to a human per body region in real-world crashes. The different AIS values per body region can be combined to one overall injury criterion, known as the Injury Severity Score (ISS). The ISS predicts a percentage of mortality [7].

In this research, the interval in which the HIC reaches a maximum value was set to 36ms. This time interval affects the HIC calculation. In case of hard contact impacts this interval can better be 15ms, which is also applied in [5].

CONCLUSIONS

The project described in this paper originally started with the aim of reducing injuries in car-to-truck frontal collisions by improving the compatibility of the truck front structure. Evaluation of a new truck front design is usually done by full scale testing using a passenger car with a dummy installed. This is a limited, costly and complicated way to obtain a feeling about possible reduction of injury to car occupants. Therefore a simplified and less costly method was developed by using a generic loading device replacing car and dummy, and by doing computer simulations of these crash tests in order to evaluate more parameters which are involved in these collisions.

Although the national accident database includes 5 years of data, the amount of data related to car-to-truck frontal collisions is relatively low (433). Especially the number of in-depth cases from which detailed information about the accident is subtracted is low (53). This has consequences on the accuracy of the number of fatalities and on the fatality reduction rate. However, it is also recognized that by inclusion of new data (additional years) from the national accident database, the composition and distribution of the fatalities will also change, because of introduction of newer car and truck designs, new roads and road design, etc. In the current method the use of an MPDB replacing the car is therefore an advantage, but the influence of new statistic information should be faced.

The size of the standard PDB was adapted and a bumper element was added. The size was changed in order to have a better structural interaction with the energy absorbing front of the truck (the FUP). The influence of height reduction of the PDB may be small for the application in assessing car self-protection and partner protection. The bumper element was added to the PDB in order to have better load spreading from the (isolated and limited contact area) FUP to the MPDB. Especially in the lower offset cases the FUP, without any adjacent structures, may penetrate the honeycomb of the PDB till the end, resulting in bottoming out. A bumper element may reduce this, however, the possibility of aggressiveness evaluation is abolished.

The method described in this paper allows a quick evaluation of new truck front designs with respect to fatality reduction. Assuming that the accident statistics do not change abruptly from one year to another, the estimated reduction of fatalities might be valid for some time, especially when the fatality reduction rate is used.

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