Evaluation Methods for the Effectiveness of Active Safety Systems with respect to Real World Accident Analysis

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ABSTRACT

Starting around 1980 with the introduction of ABS, followed in 1995 with the presentation of ESP/ESC, and recently with the development of radar and camera based driver assistance systems, the automotive industry has introduced a great number of electronic systems with the specific goal of enhancing the active safety of vehicles.

The paper discusses evaluation methods for the effectiveness of modern Active Safety systems with respect to:

- Analyses of accident statistics
- In-depth studies on real world accidents
- Case by case evaluations of real world accidents and/or field studies
- Performance tests and measurements on test tracks

The paper gives an overview of the latest methods with their benefits and limitations as seen by an OEM.

INTRODUCTION AND MOTIVATION

One of the first electronic systems that was introduced to enhance Active Safety was ABS. The degree of innovation of the system at that time made it necessary to demonstrate the specific characteristics and highlight the benefits that ABS delivers in critical driving and braking situations. There was a need to convince authorities to homologate and consumers to purchase this innovative technology. Figure 1 shows one of the typical demonstrations that displayed the benefits of ABS controlled braking vs. conventional braking.

Figure 1: ABS Demonstration 1978

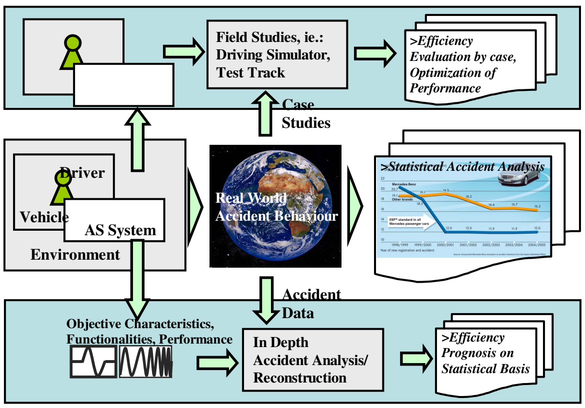
However, not only practical demonstrations were done at this time. Already, attempts were made to quantify the accident reduction potential of ABS on the basis of statistical accident data [1]. In this study, an effect of 4 to 7% accident reduction due to the introduction of ABS was assumed. Unfortunately, the attempts to confirm this prognosis in retrospective accident analyses were not successful. Only many years later it was possible to create a successful retrospective accident analysis – for a different system, the Electronic Stability Program (ESP) / Electronic Stability Control (ESC) [2, 3, 4, 5, 6].

The motivation to show potential benefits of Active Safety systems has grown over the years due to the increased complexity and functionality of the systems. Consumers need to be informed and motivated and authorities are not only in the position to homologate but also play an important role of raising consumer awareness and even implementing legislation. Additionally, rating organizations and insurance companies have entered the scene to play their part in enhancing the market penetration of certain Active Safety systems. All these interested parties have a strong interest to assess the efficiency of Active Safety systems.

EVALUATION METHODS FOR THE EFFICIENCY OF ACTIVE SAFETY SYSTEMS

Figure 2 gives an overview of potential methods that can be used to evaluate the efficiency of Active Safety systems.

Figure 2: Examples for Efficiency Evaluation of Active Safety



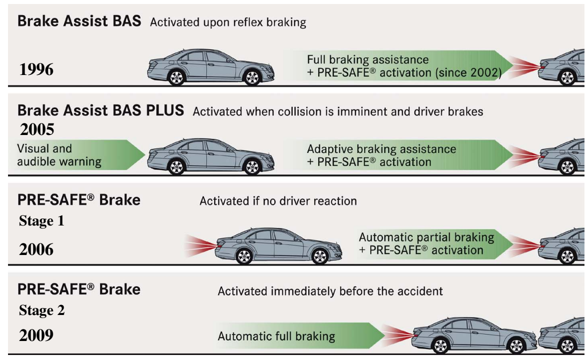
Defining and predicting efficiency is a very challenging task: An Active Safety system cannot be analyzed "stand alone" since it functions together with both the driver, his perception and specific driving skills and the vehicle with its specific dynamic characteristics. So even when the objective characteristics, the functionalities and the performance of an Active Safety system can be defined and measured, they are by far not sufficient to quantify system efficiency. In this paper the following approaches will be discussed:

- Analysis of accident statistics
- In-depth studies of real world accidents
- Case by case evaluation of real world accidents and/or field studies
- Performance tests and measurements on test tracks

Which method is applicable depends on the system type and functionality.

Examples are given for several Mercedes-Benz braking assistance systems in Figure 3.

Figure 3: Mercedes-Benz Braking Assistance Systems from BAS to PRE-SAFE® Brake



The Brake Assist BAS interacts with the driver: If the drive applies the brake pedal in a way which is characteristic for emergency reactions, brake pressure is automatically increased to provide full deceleration. This system is complemented by the radar based Brake Assist Plus. It warns the driver in case of an imminent collision danger and - upon pedal application - increases the brake pressure to the level that is necessary to avoid the accident. PRE-SAFE® brake reacts if the driver ignores the visual and audible warning and initiates a partial braking (stage 1) and a full deceleration (stage 2). PRE-SAFE® brake stage 2 is activated approximately 0.6s before the impact, i.e. when an accident can not be avoided. PRE-SAFE® brake stage 2 is designed to mitigate the crash outcome and can therefore be regarded as an "electronic crumple zone".

ANALYSIS OF STATISTICAL ACCIDENT DATA

The most impressive method to prove and quantify the efficiency of an Active Safety system in real world accident scenarios is clearly the retrospective accident analysis. The excellent results that could be obtained for the Electronic Stability Program (ESP) in numerous studies [i.e.: 2, 3, 4, 5, 6] are a very good example. They were so impressive that they caused the brake-through of this assistance system.

Unfortunately, it was not possible to verify the real world performance for any other Active Safety system in a comparable magnitude. The main challenge is identifying statistically relevant changes in accident behavior between cars with and without a system that project beyond the noise of accident data. ESP was rapidly introduced over numerous model lines and hence the effect on accident statistics was so significant.

A further example of a successful retrospective accident analysis is the efficiency of the Mercedes-Benz Brake Assist BAS. BAS was introduced in 1996 and became standard equipment on all Mercedes-Benz passenger vehicles by 1997. Again, a very steep gradient of introduction allowed to clearly distinguish between cars with and without Brake Assist, allowing a tangible evaluation of the effect of BAS on rear end crashes in accident statistics.

Figure 4: Analysis of Accident Statistics, Brake Assist (BAS): Fewer Rear-End Accidents.

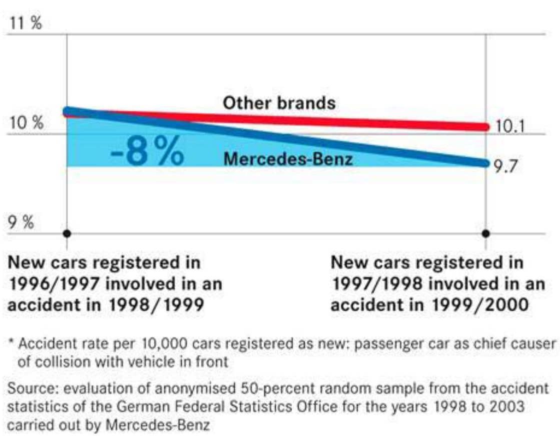


Figure 4 shows an 8% decrease in rear end crashes after the introduction of BAS.

Of course, a retrospective analysis of accident data is only possible if a system has been on the market long enough to provide a sufficient market penetration. Before and during the introduction of a new Active Safety system only prospective methods are helpful.

IN-DEPTH STUDIES OF REAL WORLD ACCIDENTS

If a retrospective accident analysis is not successful for given systems or not possible for new systems, in-depth studies of real world accident can be very helpful. Real world accidents can be reconstructed and re-analyzed considering the assumed effect of a specific Active Safety system. For that purpose the accident data needs to provide detail (including driver behavior). The German GIDAS data base [7] is a good source for this purpose. As an example, it was possible to recalculate to positive effect of Brake Assist on pedestrian accidents on the basis of GIDAS data [8]. This study and similar other studies formed the basis for the European legislation on pedestrian protection that includes the mandatory fitment of BAS on passenger cars [9].

A different example is the recently published prognosis of the efficiency of BAS PLUS on real world accidents [10].

Figure 5: Efficiency - Prognosis on Basis of Real World Accident Analysis (GIDAS)

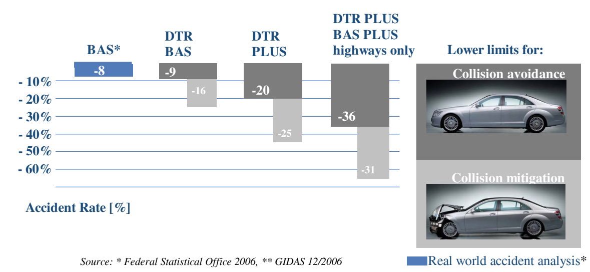


Figure 5 shows that the predicted efficiency of BAS on the basis of GIDAS data is very similar to the value that was obtained in retrospective statistical accident data analysis. BAS PLUS, a system launched in 2005, shows a prognosis of 20% accident reduction and additional 25% of accidents with mitigation effects. Values for highway- and Autobahn-scenarios only are even higher.

This approach is associated with significant analysis effort, but will gain importance in future for system development and optimization as well as for creating positive public awareness of modern safety technologies.

CASE BY CASE EVALUATION: REAL WORLD ACCIDENTS AND/OR FIELD STUDIES

Real world accidents can also deliver very valuable information when analyzed case by case.

Mercedes-Benz has a long tradition in real world accident analysis. Mercedes accident engineers have been systematically evaluating severe accidents with occupant injuries on-site since 1969. An extremely detailed database, only comprising Mercedes-Benz passenger vehicles and – more recently – light commercial Mercedes-Benz vans, has accrued over time. Even though comprising a comparatively small number of ca. 3,800 cases, the underlying database is an invaluable resource for product real world performance monitoring and improvement that no accident other study can offer.

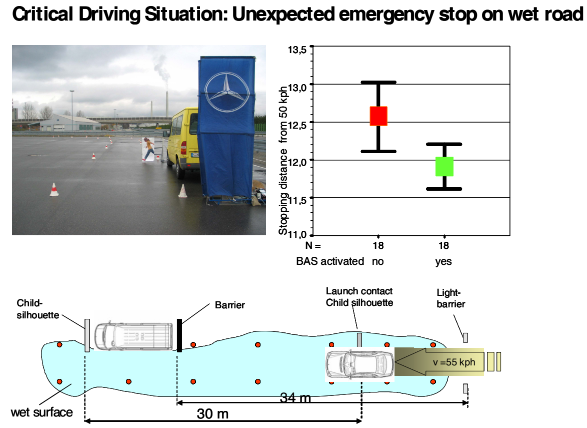
But such studies of real world accidents cannot only show optimization potential for Passive Safety. Accident reconstruction delivers inspiration for innovative Passive and Active Safety systems. The idea of exploiting the PRE-SAFE® phase, a time between departure from safe driving and the actual accident, was directly derived from the Mercedes-Benz accident research. Accident analysts showed that the PRE-SAFE® phase was of considerable duration, exceeding the time available for crash-activated devices by orders of magnitude. This marked the advent of reversible safety systems, most prominently the reversible PRE-SAFE® seat belt tensioner.

The reconstruction of the accident scenario under the assumption that a specific Active Safety system was present allows a prediction of the systems effect on the specific case.

Additionally, the reconstruction of real world accidents can be used to create artificial or virtual scenarios for field tests with normal drivers on test tracks or in the driving simulator.

An example for a typical critical driving scenario that can be used for field studies on test tracks is described in Figure 6. A driver who is not prepared for the event experiences an unexpected emergency braking situation when an obstacle crosses his driving path. The emergency bracing reaction of the driver and the resulting stopping distance can be measured. The results with BAS and without BAS can be evaluated and compared.

Figure 6: BAS Efficiency on Test Track



In this case a significant enhancement of braking performance and reduction of stopping distance was observed for test runs with BAS.

Most of the relevant accident scenarios that can be derived from accident analyses are of a much more complex type, including other traffic and more sophisticated driving situations. In these cases a driving simulator can be used to gain repeatable results under complex conditions without risk for the test persons.

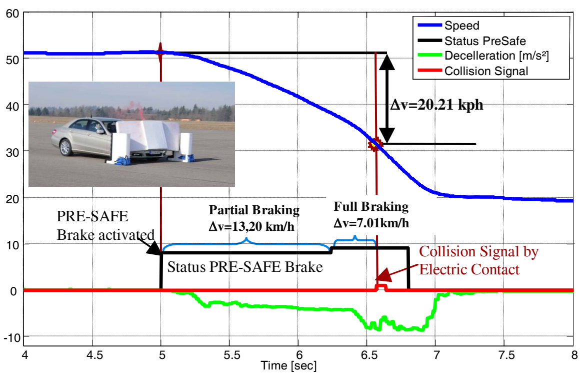
Figure 7: BAS PLUS Efficiency in Driving Simulator

Figure 7 shows the result of a study in the Daimler driving simulator in Berlin. 110 drivers experienced typical critical situations derived from accident research. BAS PLUS lead to a reduction of the accident rate of 75% in these specific situations compared to the conventional BAS.

PERFORMANCE TESTS AND MEASUREMENTS ON TEST TRACKS

All the effects that Active Safety systems have in real world accident scenarios as well as in field studies on test tracks or in simulators are of course related to their specific functionalities and objective performance. Functionalities and performance of the Active Safety system are usually well known to the OEM and are used as input parameters for all of the above described evaluation methods. Nevertheless, objective tests are necessary for demonstration and especially for validation purposes, e.g. in combination with ratings or with homologations. Objective tests and minimum performance levels have been defined for Electronic Control Systems [11] and also for BAS [9].

Figure 8: Measurement of Speed Reduction by PRE-SAFE® Brake



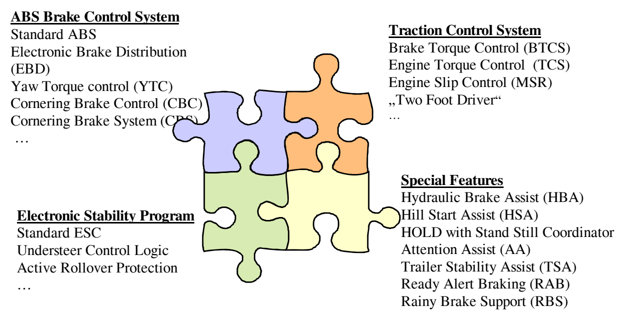
The result of a typical performance test of the recently launched PRE-SAFE® brake stage 2 is shown in Figure 8. The diagram shows the result of a critical approach to a stationary obstacle that simulates a vehicle. Even without any driver reaction the vehicle speed is reduced from 54 km/h to 34 km/h. Partial braking of PRE-SAFE® brake reduces the speed by 13 km/h, PRE-SAFE® brake stage 2 delivers an additional 7 km/h reduction under these circumstances. This translates into an energy reduction of almost 63% which is not only beneficial for the occupants of the car equipped with PRE-SAFE®, but also for the passengers of the other vehicle.

LIMITATIONS

Although the functionality and the performance of Active Safety systems form the basis for their real world efficiency, they are not sufficient to describe all relevant effects and will not allow an efficiency prediction. Active Safety systems interact with the driver, they support the driver, they help to avoid mistakes and they interact with the vehicle and the environment. A full forecast of their potential is only possible with respect to the complete relation of driver-vehicle-system-environment (Figure 2). Statistical methods or field tests can be an approach to that aim, but a test track test alone will not be sufficient.

Even the inviting opportunity to at least compare different Active Safety systems with similar functionality is questionable. Active Safety systems are very complex; they usually contain a variety of sub-functionalities. As an example, figure 10 gives a rough overview of the functions that are contained within a current Electronic Stability Control system.

Figure 9: ESP® Functions



All these sub-functions are optimized and developed during a development phase that takes several years. Each function is tested under numerous test conditions and situations [12, 13, 14]. It is not realistic that this overall functionality and performance be evaluated on basis of a limited number of tests.

This is even more important with respect to real world accident scenarios, since it is not clear in most cases which sub-function had the greatest real world effect.

Finally, even systems that more or less autonomously react without driver interaction cannot be evaluated completely with simple tests. The test result of PRE-SAFE® brake in Figure 9 may serve as an example: Evaluating the performance of this system on the basis of a "positive test" can be very misleading. In case of the PRE-SAFE® brake the "positive-false" performance is by far the greater challenge.

“Positive-false” implies that the system may not activate in non-critical real world situations. It is not sufficient to create a system that brakes as often and as hard as possible. The challenge is to overrule system activation in all non-relevant real world situations that might occur, and to activate it only when really necessary. To verify this, Mercedes-Benz tests new systems under realistic traffic situations (Figure 10).

Figure 10: Mercedes-Benz Real World Testing of Active Safety Systems

Normal drivers use specially equipped cars in real traffic in several countries on different continents to evaluate the system performance under real world conditions. In a first step the test cars are equipped with the system in a passive state, i.e. the sensors, controllers and algorithm are on board and active, but do not lead to a vehicle system intervention. The cars are equipped with several sensors and video cameras that allow the evaluation of driving situations, driver actions, and system reactions. In a second phase the system is active when driven on public roads. PRE-SAFE® brake for example experienced a total test volume of more than 1 Mio. km in real traffic. The collected test data is stored and used to recalculate and optimize the effect of different algorithms offline.

SUMMARY AND OUTLOOK

The evaluation of the effectiveness of Active Safety systems is possible on several levels of abstraction. Basic tests are functionality and performance tests on test tracks that can be used for development or demonstration purposes. A broader view of the system's performance, including the driver-system interaction, can be gained by field tests on test tracks or in a driving simulator, ideally on the basis of scenarios derived from real world accidents. Statistically more significant are accident reconstructions on the basis of in-depth accident data analyses. The probably most accurate efficiency evaluation is the retrospective statistical accident data analysis that delivers the most reliable results, but is not viable in most cases and not feasible for new systems.

The effectiveness evaluation of Active Safety systems has shown huge impact in the past, especially with respect to ESP®. It can be expected that in future, the importance of these kinds of evaluations will continue to increase. Motivation of this is the demand to raise consumer awareness by manufactures, authorities, insurance companies and others.

This consumer information is required to increase the acceptance and market penetration of effective Active Safety systems for the achievement of the overall goal: To increase traffic safety, i.e. to reduce the number and severity of accidents and to save as many lives as possible.

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FROM 15% TO 90% ESC PENETRATION IN NEW CARS IN 48 MONTHS - THE SWEDISH EXPERIENCE

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ABSTRACT

Electronic Stability Control (ESC) has been proven to be one of the most effective safety technologies, reducing serious crashes substantially. In Sweden the first attempt to stimulate the sales of ESC started in mid 2003. By using several market oriented methods the penetration rate on new cars reached over 90% 48 months later and is by late 2008 around 98%.
In this paper, the methods to increase fitment of ESC, are presented, including actions from the government, administrations, insurance companies and the automotive sector. The results show that a structured implementation strategy can be very successful.

BACKGROUND

Electronic Stability Control (ESC) has been proven to be very effective in reducing crashes related to loss of control (Erke, 2008, Ferguson, 2007). While follow up studies from real life crashes show a varying effect, it is in general large and consistent. The size of the effectiveness is larger than many other safety systems, like airbags, and is sometimes called the biggest step in automotive safety since the introduction of seat belts. Such statement seems a bit loose in what is defined as safety systems, but nevertheless points at the fact that a new technology has quickly established itself as a major step in history, and that there is hardly any controversy about the effectiveness. This is in contrast with ABS (Antilock Braking System), introduced on the mass market in the beginning of the 1990s. Despite several studies with different study design, the effectiveness seems to be very small, if not completely ineffective. (Burton et al. 2004)

The first studies of the effectiveness of ESC were published in 2003. Several studies followed in 2004 and 2005 establishing a scientific ground for declaring that ESC was effective. Several of the studies have been published in peer review journals, and several study methods have been used. Given that the first mass market introduction of ESC took place in 1998 with the Mercedes A Class, quickly followed by a few other small or midsized high volume vehicle, studies might have been done earlier.

The implementation of ESC has so far been based on marketplace growth and on some markets by supportive interventions. Legislation has not yet been brought in, but decision has been made to make ESC mandatory in the USA in 2012 and signals have been sent from the EU as well (EU Commission 2008).

The rate of penetration of ESC in new cars seems to vary substantially across the world, and also on markets close to each other or close in market structure in terms of size and category of vehicles (Euro NCAP 2008). While these results are hard to explain given that cars are more or less global products, it is interesting to find the characteristics of a country with an almost 100 % penetration (97.9 %, December sales 2008), and what might have led to an extraordinary quick process, without legislation or other significant incentives. In most other European countries the fitment rate is much lower. The only country with a similar rate as Sweden is Denmark. Denmark has a totally different approach to increase the fitment rate by economic incentives for those buying a new car fitted with ESC.

The purpose of this paper is to describe and discuss the implementation process of ESC in Sweden.

ACTIONS TO IMPROVE PENETRATION

The first mass market car with ESC was introduced late 1998. Following an event in Sweden involving a journalist tipping over the car in a manoeuvre test, the car was recalled and ESC was added to improve handling. ESC was from then on gradually implemented on executive mid size and large cars and reached a 15 % new car sales penetration in mid 2003.

The first study of the real life effectiveness of ESC was presented in March 2003 by the Swedish Road Administration (SRA) and Folksam insurance company in cooperation with the Swedish magazine "Auto, Motor och Sport".

The results had been known by the partners since early 2003, and would have been presented in June2003 at the ESV Conference, but the results were considered so sensational that the presentation was brought forward. The study was later presented at the ESV conference and also published in scientific press (Tingvall et al. 2003, Lie et al. 2004).

The organisations involved also took the unusual step to take action from results of only one study. A recommendation was issued at the same time stating that "all car buyers are recommended to choose a car with ESC".

The results and the recommendation caught major media interest. At the same time, purchasing and rental car policies for SRA and Folksam operations were changed so that all new cars bought from the date of the presentation should have ESC. The policies also changed and were stating that in the near future all cars rented for short term or long term renting and used by staff of Folksam and SRA must have ESC.

This decision was taken to influence the rental car market that has a fair market share for new cars, in the order of 7-8 %. The car rentals made by the Swedish insurance industry accounts for 50% of all car rentals. The change in policy also was intended to influence other fleet buyers to change their policies.

Later in 2003, the first screening of how car manufacturers and importers of cars had reacted and to what extent ESC fitment was increasing, was made by SRA. Some manufacturers and importers were contacted by SRA to discuss their plans for ESC fitment, especially those who were to introduce new models. The intention was to get in touch with the market departments to show the interest in ESC and thereby possibly influence their decision to make ESC standard fitment. It is likely that several manufacturers and importers changed their intended decision after those contacts. The key message from SRA has been that ESC should be standard equipment for as many models as possible.

Late 2004, when more scientific evidence showed that ESC was highly effective (Dang 2004, Farmer 2004), the Director General of SRA sent a letter to all manufacturers and importers asking them to as quickly as possible stop selling cars without ESC. This letter had of course no legislative or any other legal basis, it was simply a request based on the scientific findings.

In 2004 and 2005, the Swedish Occupational and Health Safety (OHS) Administration brought in ESC in their checkpoints when employers were asked about a systematic improvement of OHS. This of course exposed many organisations to the urgency of ESC. By the same time, many fleet buyers had picked up ESC in their purchasing and rental car policies. At this point of time, almost 70 % of new car sales had ESC.

In 2004, SRA as a member of Euro NCAP proposed that ESC should be promoted through Euro NCAP, which Euro NCAP also did in 2005 as a "strong recommendation to consumers". This was later followed by the involvement in ChooseESC, the major campaign from e-safety, FIA, the EU Com and many others.

A new scientific study of the effectiveness of ESC was presented by SRA and Folksam in 2005 (Lie et al. 2005, 2006), demonstrating both more long term effects as well as more broken down effectiveness estimates. At the same time, a special commission on crashes in wintertime was formed in Sweden, with members form many stakeholders, like the tyre industry. The commission also issued a recommendation on ESC and all stakeholders took a decision only to buy and use cars with ESC. Both the results of the new study and the results of the commission were brought to media attention (SRA 2005).

In 2006 Folksam made a first evaluation of ESC fitment rates on all car models on the Swedish market (Folksam 2006). It showed that 33% of the models for sale were not fitted with ESC as standard. In 2007 a second evaluation was made. The second study was made in a same way in several EU member states within the RCAR (Research Council for Automobile Repairs) p-safe group. The activity was made as a bench marking aimed at reaching the same fitment rates within the countries involved. In December 2007 96% of all new cars sold in Sweden was fitted with ESC. In 2008 a third review was made that showed improvements for all countries. The largest improvement, however, was shown for Sweden that already from in 2006 had a leading position.

In 2007, Folksam Insurance Group adjusted their premiums according to the fitment of ESC. The differentiation was set to 15 %. SRA at this time initiated that the national vehicle registry should contain the possibility for car manufacturers and importers to on a voluntary basis register all cars with ESC. In 2007 when the government as a whole made a purchasing contract with all interested importers of cars, ESC was a mandatory requirement. In 2008 this will be expanded also to all vehicles except HGV.

In December 2008, the fitment rate was 97.9 % and will most probably rise to almost 99 % in 2009. The only current signal that is not promising is that one importer plan to sell a low cost vehicle without ESC (Dacia/Renault). There is no other sign of a process moving backwards.

What seems to be most critical for the implementation of ESC is the following

- The scientific results. Without these findings there would be no action from all stakeholders involved
- The involvement of media. Media has been involved from the beginning, even in presenting the first scientific results, and followed this up by mentioning ESC in most car tests and asking car manufacturers and importers when new cars are launched
- The purchasing behaviour from the stakeholders involved. SRA and Folksam actually only using cars with ESC sent a signal that the issue was serious and created a demand from the market place.
- The constant contact with manufacturers and importers about their plans showing the seriousness from both the government and insurance
- The constant monitoring of the implementation process and the benchmarking to other countries.

In order to set the process, all these identified steps should be taken. What is crucial is the scientific evidence.

DISCUSSION

It is obvious that new safety technology can be implemented successfully through the market place, but that the society must act accordingly. To simply leave the issue to the suppliers of new technology, and the customers, is not likely to work. The varying results across countries are probably a sign of this.

A number of important steps are mentioned, but it seems impossible to start to intervene in stimulating the market without scientific evidence. While it could be research initiated by governmental bodies, NCAP organisations or insurance companies, the automotive industry could also play a more active role. In this particular case, with ESC, there were attempts from industry to publish results, but hardly in the way that the research community accept. There are, however, examples of research published under the scrutiny of peer review from industry. Euro NCAP has initiated a process whereby car manufacturers can demonstrate the safety performance to the society in a staged process (Beyond NCAP). This is an opportunity to show safety benefits at a quite early stage. Nevertheless, governments should also engage in collecting information and make that available for research. It is still extraordinary strange that the first follow up of ESC came from Sweden, one of the smallest countries in Europe. In countries like Germany, the UK, France, the US and probably more, studies of the effectiveness of ESC could have been done much earlier, probably around 1999 or 2000. Combining data from these countries could also have been an option. While the analysis of ESC is quite straightforward and could be quite easily done on mass databases, there is still no attempt from some countries to be involved in follow-up studies of new technologies.

The behaviour of the organisations sending the signal to the society is probably of great importance. While this seems natural, also from the responsibility under the OHS act, few governments seem to act in such a way. Probably even car manufacturers do not act in this way. Corporate behaviour probably played a major role in the implementation in Sweden, and probably worked in a twofold way. First of all, it is sending a signal to the market from organisations that would be considered as serious. Secondly, it intervenes in the marketplace. Rental cars are a quite substantial part of new car sales, and would normally be less specified vehicles. When this part of the market is triggered it has an influence on the rest of the cars specified by the manufacturer and importers. Not having ESC as an option at fair price or standard equipment to the rental car market and governmental fleets leaves a portion of the market outside.

The contact with manufacturers and importers is if great value, and without their support the implementation would not be so successful. Constant monitoring of their behaviour is also important, to build trust that not anyone of them returns to lower specified vehicles. The only case where this seems to happen in Sweden is with one importer, Renault/Dacia. The initiative of Euro NCAP on integrating ESC in the rating scheme plays a role.

Differentiation of insurance premiums could be very important, but is also based on scientific evidence.

Bench marking between countries is also a tool to be used to increase fitment rates. The activities within the RCAR frame have indicated a general increase in fitment rates.

There will be a plethora of new systems and technologies that enters and will enter the market. They are likely to be introduced in the form of optional equipment or on individual car models, and the market will have some problems in choosing what is effective. The society should take a much bigger role in stimulating effective systems and develop implementation methods. In this paper, quite simple methods were used, but there might be systems that will be more complicated to introduce, such as alcohol systems. In such cases, there might be an opportunity to test and use economic incentives as well, something that obviously was not needed for ESC.

While legislation to some is in competition with market oriented implementation, it should be seen as a complement. When the market has matured, legislation is a natural next step, but introducing the idea about legislation too early could be detrimental to rapid implementation. It could slow down the process and also build up resistance in the society as well as slowing down technological development. Each state should instead see the responsibility to act on the market before legislation is enforced.

CONCLUSIONS

- It is obvious that new safety technology can be introduced massively through quite simple methods – in Sweden the ESC fitment on new cars is more than 97 %
- The basis for stimulating the marketplace is scientific evidence that there is a benefit of the technology. Both industry and the society should engage in making such evidence available
- Important stakeholders, like the government and insurance companies, should act accordingly and only buy, rent and use vehicles with the technology that is effective
- Media and industry are crucial stakeholders in the process

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INJURY AND STRUCTURAL TRENDS DURING 12 YEARS OF NCAP FRONTAL OFFSET CRASH TESTS

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Paper Number 09-0374

ABSTRACT

64km/h frontal offset crash tests are conducted by consumer crash test programs in Australia/New Zealand, Europe, the USA, Korea and Japan. Data from ANCAP and Euro NCAP crash tests are analysed and trends for head, chest and leg protection and structural performance are discussed.

Vehicle designs have evolved to provide better occupant protection in frontal offset crashes. Consumer crash test programs have accelerated this process.

INTRODUCTION

The Australasian New Car Assessment Program (ANCAP), US Insurance Institute for Highway Safety (IIHS) and Euro NCAP have conducted 64km/h offset crash tests since the mid 1990s. Japan NCAP and Korean NCAP also conduct this test. In 1999 ANCAP aligned its test and assessment protocols with Euro NCAP and began republishing applicable Euro NCAP results.

This paper sets out the results of an analysis of offset crash test results for 332 models of passenger vehicles. Results have been analysed by year model to check for trends over 12 years of testing (1996 to 2008).

DATA SOURCES

Crash tests conducted by Euro NCAP and ANCAP have been analysed. Table 1 sets out the number of models evaluated by year and vehicle category. Three categories have been used in the analysis:

- Cars - Passenger cars, multi-purpose passenger vans, sports cars
- SUVs - Sports Utility (four-wheel-drive) vehicles
- Commercial ("Comm") - Utilities ("pick-ups") and goods vans

Table 1. Sample Sizes

Year Model	Cars	Comm.	SUVs	All
1996	4			4
1997	9		3	12
1998	15		2	17
1999	17		1	18
2000	14			14
2001	17	5		22
2002	8		16	24
2003	26		3	29
2004	20		7	27
2005	26	11	8	45
2006	24	1	11	36
2007	28	5	5	38
2008	30	9	7	46
Total	238	31	63	332

Sample sizes in some cells are small, resulting in some uncertainty with derived trends. Also it should be noted that NCAP organisations sometimes conduct campaigns targeted at particular groups of vehicles and this can affect the derived trends.

All injury measurements are for Hybrid III 50%ile males.

RESULTS - INJURY MEASUREMENTS

Driver HIC

Figure 1 shows the trends for driver Head Injury Criterion (HIC36). There is a slight downward trend. It is rare to see HIC above 650 (the Euro NCAP lower limit) after 2001. The few cases above this value generally do not have a driver airbag. ANCAP is likely to have influenced the uptake of airbags, particularly with commercial vehicles that can meet Australian regulations without an airbag.

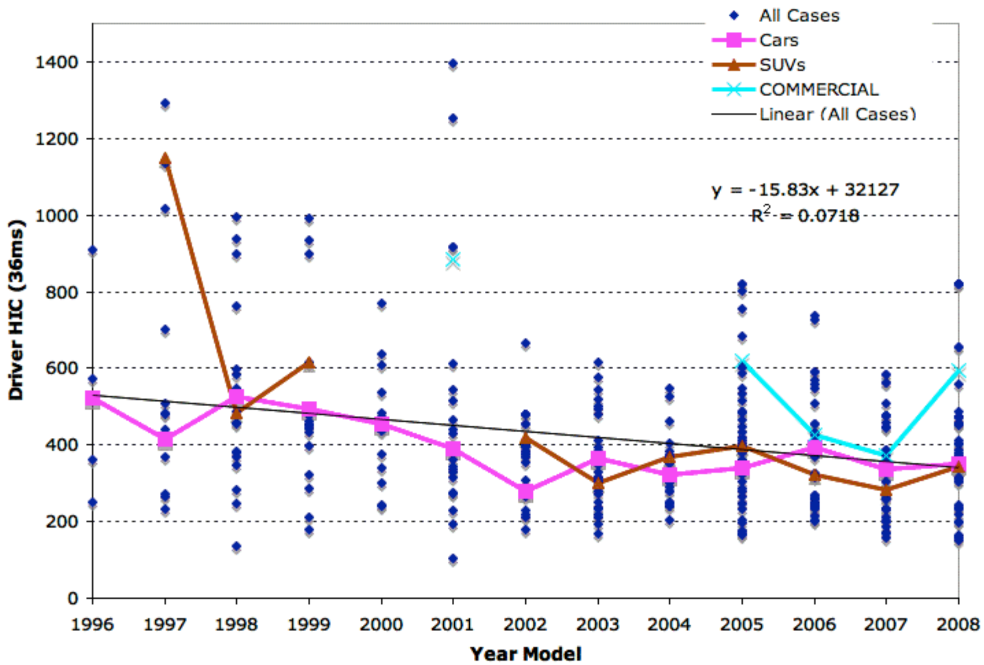

Figure 1. Trends in Driver HIC

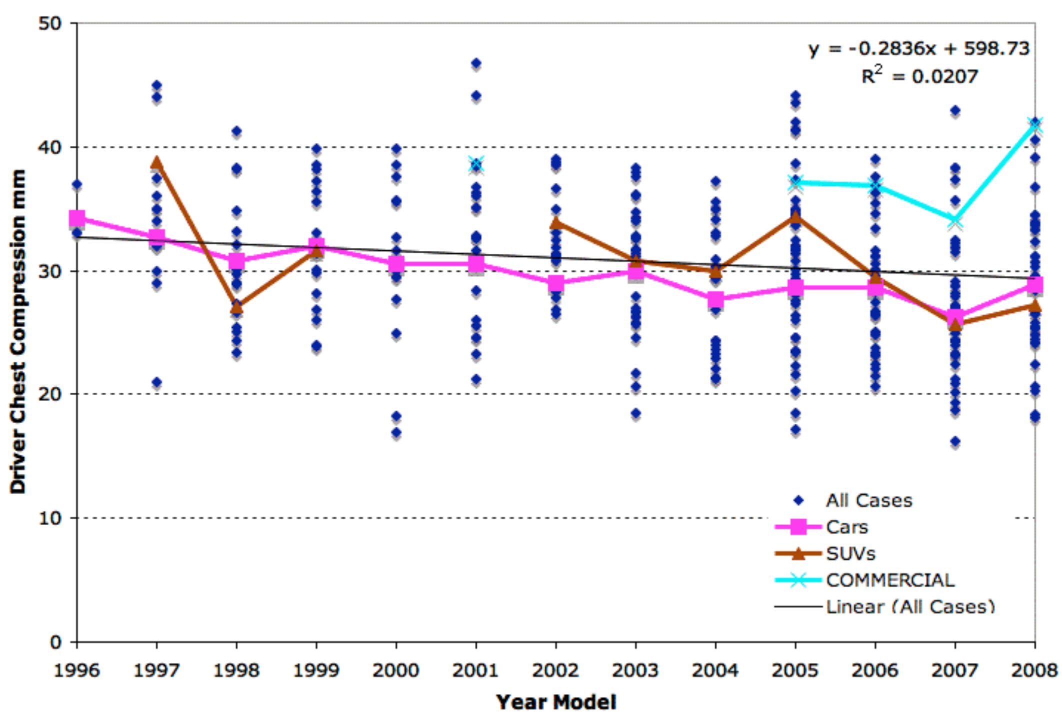

Figure 2. Trends in Driver Chest Compression

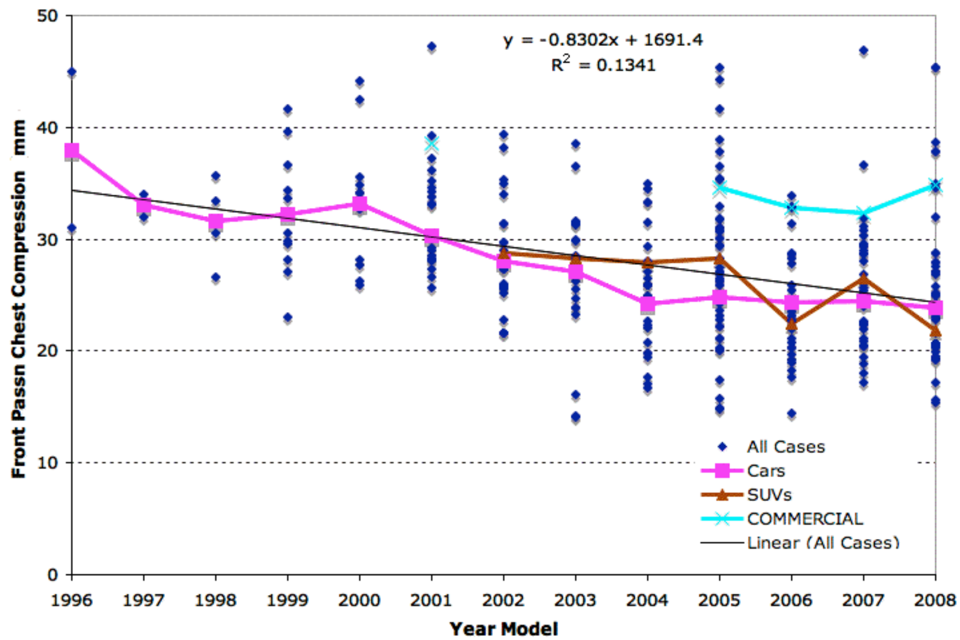

Figure 3. Trends in front passenger chest compression

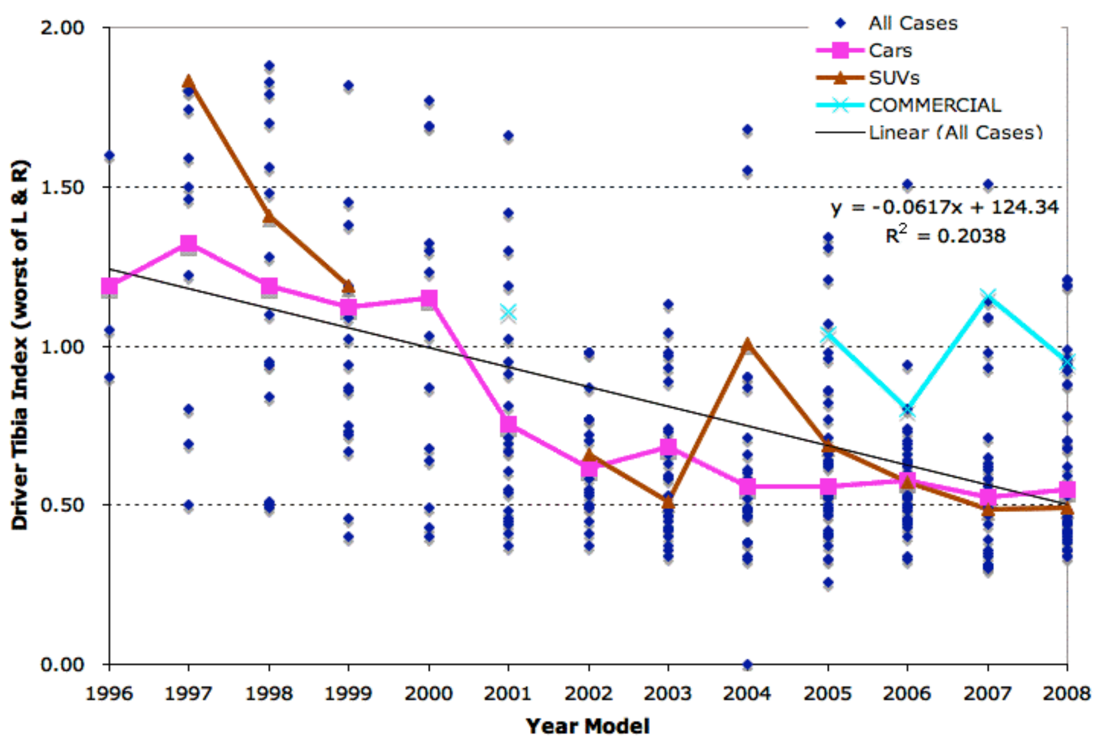

Figure 4. Trends in driver tibia index

Chest compression

Figures 2 and 3 show trends in driver and passenger chest compression. The Euro NCAP system assigns a good rating for compression of 22mm or less and a poor if more than 50mm.

There is a slight downward trend for car drivers but the average remains well above the desired 22mm level.

There is a slightly stronger downward trend with passenger chest compression, compared with drivers, but the averages remain well above 22mm.

For both the driver and passenger the average commercial vehicle values are substantially higher than for cars and SUVs.

Seat belt technologies such as pretensioners and load-limiters are usually fitted to models that achieve relatively low chest compression values.

Driver Tibia Index

Four separate tibia index values are measured. The worst of these four readings is used in the analysis (as it is for scoring under the Euro NCAP protocol). Results are plotted in Figure 4. The Euro NCAP system assigns a good rating for a tibia index of 0.4 or less and poor for 1.3 or more.

The strong downward trend (that is, reduced risk of serious injury) that was evident in the 2001 analysis has continued (Paine 2001).

RESULTS - DEFORMATION MEASUREMENTS

A-Pillar Movement

Residual rearward displacement of the A-pillar (adjacent to the upper hinge of the front door) gives an indication of the integrity of the passenger compartment. Large displacements are usually associated with catastrophic collapse of the roof, driver's door and floorpan.

Euro NCAP applies a "chest score modifier" to A-pillar displacements greater than 100mm, scaling up to a 2 point penalty at 200mm displacement.

Results are plotted in Figure 5. A downward trend that was evident in 2001 has continued (Paine 2001). Commercial vehicles tend to have a larger displacement than cars or SUVs.

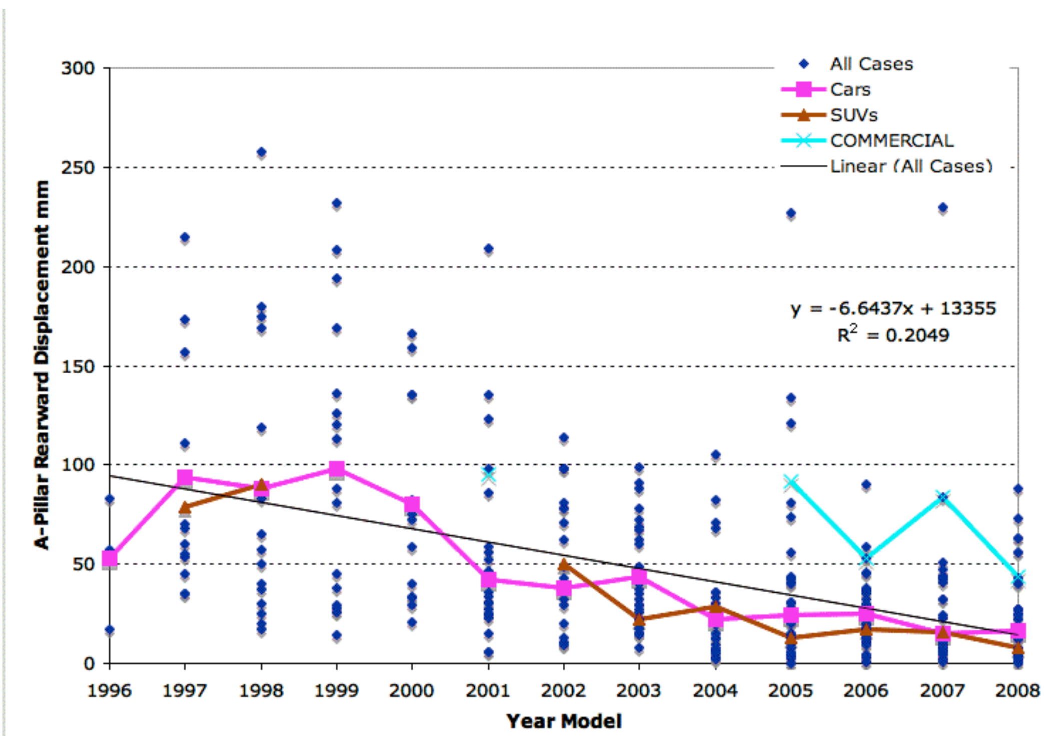

Figure 5. A-pillar rearward displacement (mm)

Brake Pedal Movement

Residual rearward displacement of the brake pedal gives an indication of potential injury to lower legs and feet. Breakaway pedal mounts are becoming common to eliminate rearward movement of pedals.

Under the Euro NCAP system a good result is obtained if the displacement is less than 100mm and a poor result is obtained if the displacement is 200mm or more. Results are plotted in Figure 6.

There is a downward trend for cars and SUVs. Commercial vehicles generally have much larger pedal displacement than cars and SUVs. In some cases it is possible that the groin of the dummy contacted a pedal that was displaced close to the front edge of the seat.

Offset score

The Euro NCAP system assigns a score out of four for each of four body regions: head/neck, chest, upper leg and lower leg. In some cases "modifiers" are applied to the scores - the scores are reduced to take into account the potential for further injury due to intrusion or stiff, sharp interior components. Figure 7 shows the trends for offset scores between 2000 and 2008.

The general trend is an improvement in offset score, indicating reduced risk of serious injury. However, there are still some cases with comparatively poor offset scores. The average for commercial vehicles remains well below that for cars and SUVs.

Vehicle body deceleration

Vehicle body decelerations were available from model year 2000 for ANCAP tests. After review of the data it was decided to use the peak b-pillar x-axis deceleration on the non-struck side because the struck side plots had some unrepresentative spikes. The non-struck side was therefore considered to be more appropriate for comparison purposes.

Figure 8 shows that there is no strong trend with peak vehicle deceleration over the eight years. This is despite the downward trend in a-pillar displacement over the same period (Figure 5). This result suggests that car designers are finding ways to manage vehicle decelerations at the same time that the cabin structural integrity is being improved.

There was no noticeable change in average kerb mass of cars over the study period (not graphed).

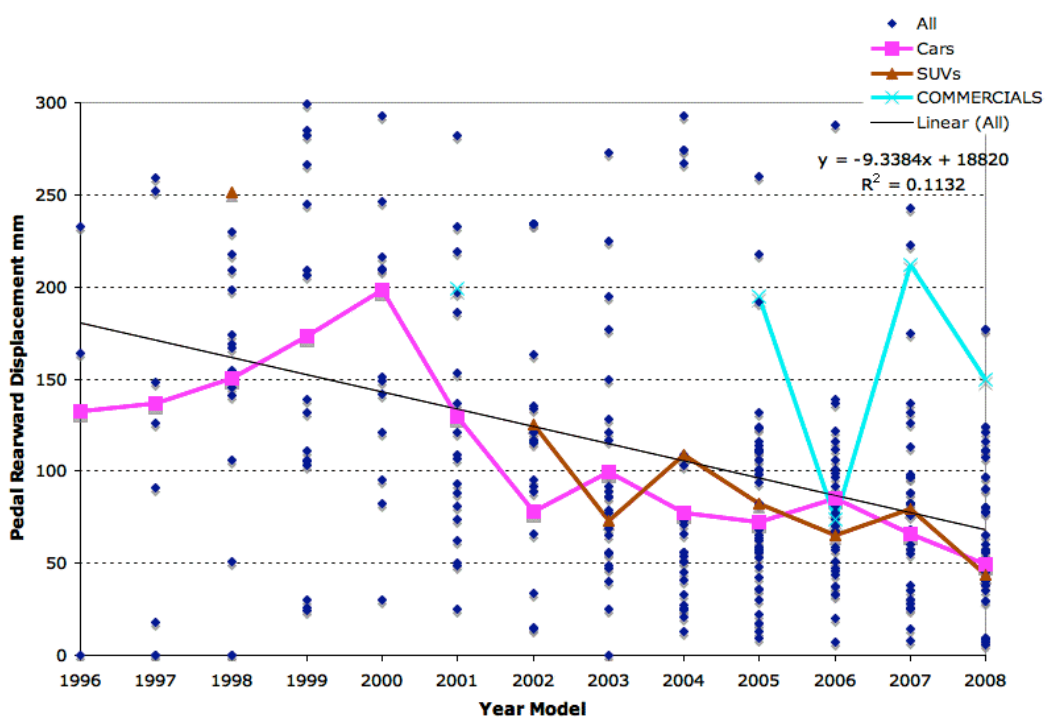

Figure 6. Pedal rearward displacement (mm)

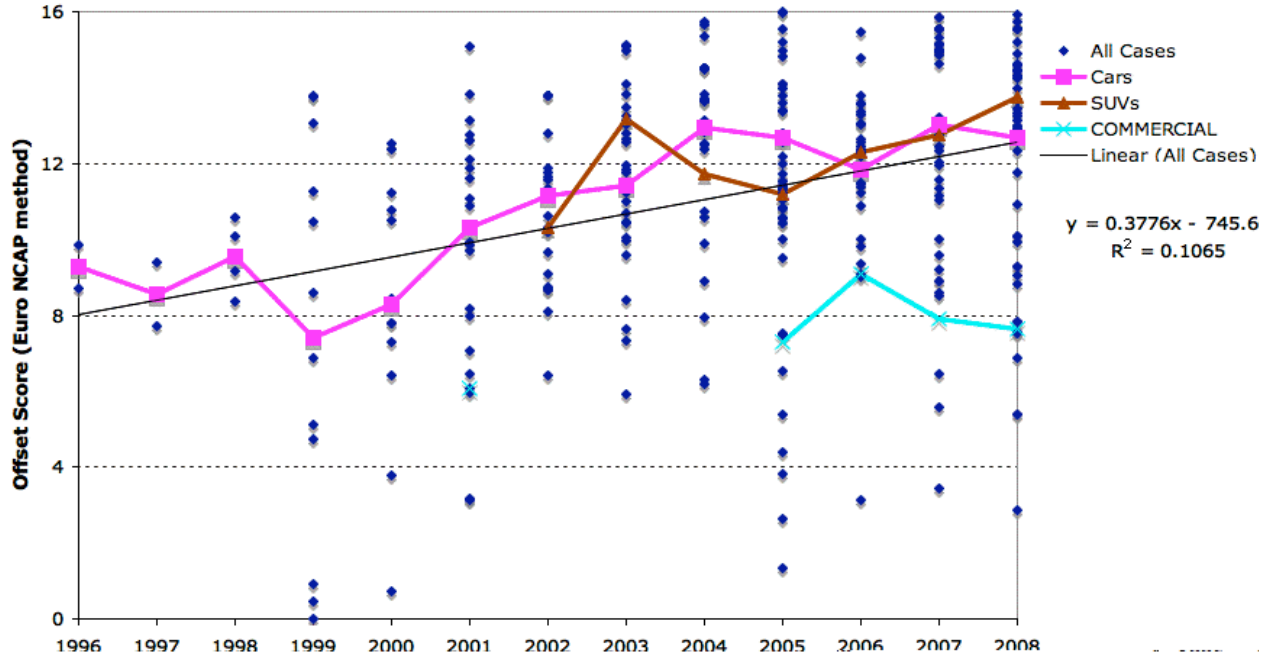

Figure 7. Trends in offset test score (with modifiers)

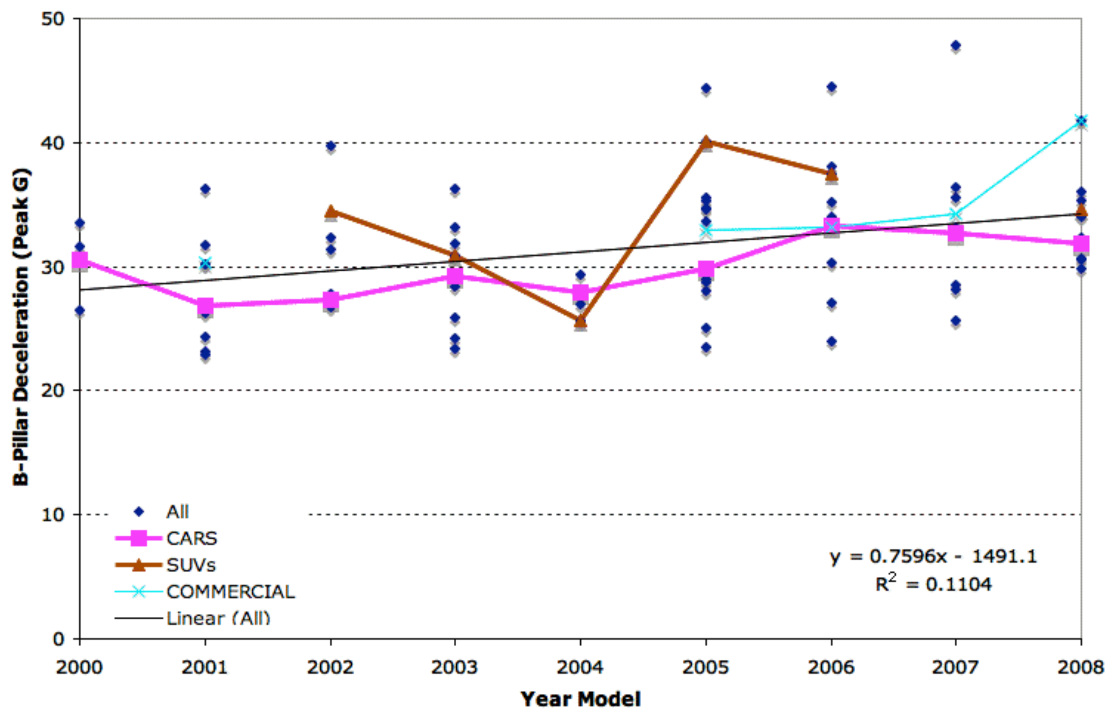

Figure 8. Trends in B-pillar deceleration (peak G, non-struck side)

TRENDS WITH TWO AUSTRALIAN CARS

ANCAP began 64km/h offset crash tests of Australian cars in 1995. The trends with two popular large cars - the Holden Commodore and Ford Falcon - are analysed below. Both models reached an ANCAP 5-star occupant protection rating for the first time in 2008 (the Commodore offset test injury scores are based on the 2006 year model).

ANCAP began assigning star ratings, based on Euro NCAP protocols, in 1999. ANCAP introduced more stringent requirements for a 5 star rating in 2004 when it required a score of at least one point in the side pole test. This effectively required head-protecting side airbags. In 2008 ANCAP added electronic stability control as a requirement for 5 stars.

Deformation trends

Figure 9 shows the trends with A-pillar displacement and pedal displacement for both models.

The Falcon pedal displacement measurements are not available for pre 2000 models but were large.

There has been strong improvement in both deformation measurements over the decade. This is also evident in the images from the peak of the crashes (see Appendix 1).

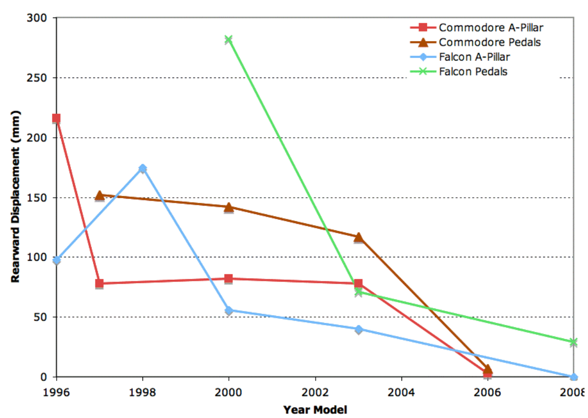

Figure 9. Deformation trends with Commodore & Falcon

Injury Trends

Driver injury measurements have been normalised using the Euro NCAP limit and the results are presented in Figures 10 & 11. The lower limit is used for HIC, chest compression and femur compression. The upper limit (1.3) is used for tibia index due to the very high values in the initial years. The Euro NCAP lower limit for tibia index is 0.4.

The Commodore shows a strong improvement in driver HIC between 1996 and 1997. Chest compression and femur compression improved gradually. Tibia index improved strongly between 1996 and 2003.

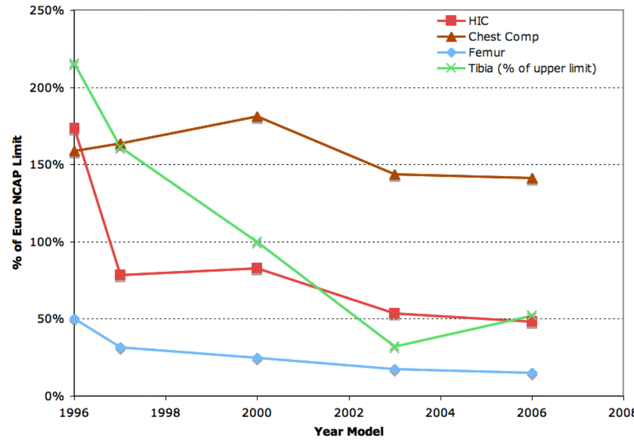

Figure 10. Commodore injury trends

For the Falcon the driver HIC, femur compression and tibia index improved strongly. Chest compression changed little.

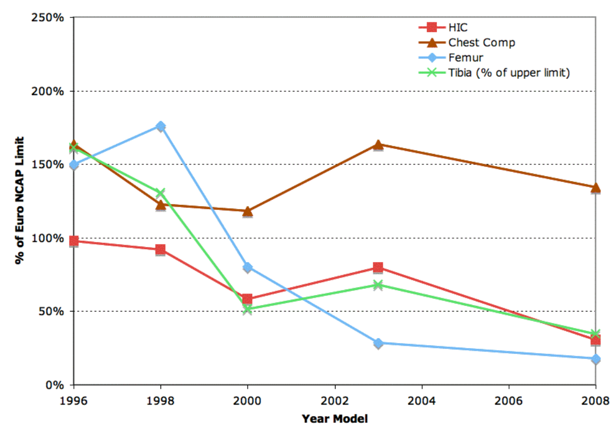

Figure 11. Falcon injury trends

DISCUSSION

The average values for HIC and chest compression for the driver, as measured in the 64km/h frontal offset crash test have reduced gradually over the 12 years of analysis. As observed in 2001 (Paine & Griffiths), some vehicles already had a driver airbag and advanced designs of seat belt by the mid 1990s.

The main effect of NCAP programs has been to influence the models that do not have these technologies and this appeared to be the case in Europe when Euro NCAP commenced. By the late 1990s, however, Australia and New Zealand were noticeably lagging in the uptake of these features, which were not essential for meeting regulations. ANCAP is therefore likely to have resulted in accelerated introduction of these features (Fildes and others 2000).

The risk of lower leg and foot injury has reduced substantially over the period of analysis. Footwell, pedal and underfloor designs continue to improve. This can be attributed, in part, to the consumer offset crash tests which can be very demanding on the vehicle structure in this region. Structures that channel crash forces around the vulnerable footwell area are evident in recent designs (Paine and others 1998). An increasing number of models have pedals with breakaway mounts or designs that move the pedal forward in the event of relative movement between the firewall and pedal mounting bracket.

Commercial vehicles

Unfortunately there remain on the Australian and New Zealand markets many models of commercial vehicle that have much lower performance than typical cars. This is a concern because these vehicles are usually used for work purposes, the drivers may have little say in the selection of these vehicles at the time of purchase and may travel many more kilometres per year than the average, increasing their crash exposure.

There are now several ANÇAP 4-star commercial vehicles for sale in Australia and New Zealand. A few commercial utilities and vans have head-protecting side airbags as an option and these may achieve a 5-star rating during 2009.

Structural performance

The analysis of vehicle body deceleration indicates a slight increase in the average of the peak B-pillar deceleration of tested models between 2000 and 2008 (Figure 8: 28g to 34g). This slight increase contrasts with major improvements in lower leg protection (Figure 4) and suggests that footwell design improvements not been at the expense of substantially higher vehicle body deceleration.

Prior to 2000 many models experienced excessive collapse of the front occupant compartment (see Figure 5 and examples in the appendix). It is likely that vehicle body decelerations did increase during this period, when cabins were strengthened and more crash energy was absorbed by the front structure.

Figures 1 and 2 indicate that front occupant restraint systems evolved to cope with these increased vehicle body decelerations. For example, seat belt pretensioners and load limiters allow the occupant to ride down the crash while controlling the loading on the human body.

Digges and Dalmotas (2007) have proposed that US NCAP introduces a 40km/h full-frontal crash test using 5%ile adult female dummies in both front seats. They note a rise in chest injuries suffered by frailer occupants in crashes of relatively low severity and suggest that occupant restraint systems appear to be optimised for the 50%ile adult male used in the 56km/h US NCAP full frontal crash test. They also note that chest compression may be more relevant for frailer occupants than the chest deceleration that is rated by US NCAP.

While comparison data was not available at the time of writing, it is possible that the Euro NCAP/ANCAP 64km/h offset test (that already rates chest compression) would provide similar incentives to the proposed 40km/h full frontal test to address the protection of frailer occupants. In particular, car designers are known to have experienced challenges in getting front occupant chest compression below the 22mm lower limit that is a "good" rating under Euro NCAP/ANCAP protocols.

Consideration could be given to replacing the 50%ile adult male dummy in the front passenger seat with a 5%ile adult female to further address the concerns about frail occupants.

Rear seat occupants

Rear seat restraint systems tend to be much less sophisticated than the front seat systems. There are no dynamic performance requirements for rear seat belts in Australian regulations. Recent analysis by Esfahani and Digges (2009) found concerns about rear seat occupant protection, compared with front seats.

Brown and Bilston (2007) found that older children could be better protected in rear seats. Seat belt geometry and dynamic performance deserved greater attention.

Mizuno and others (2007) conducted a series of full-frontal crash tests with the intention of showing the hazards of not using seat belts in rear seats. An unexpected result was that the injury measurements for a restrained 5%ile adult female dummy indicated a high risk of head and thorax injury. As a result of follow-up research it is likely that Japan NCAP will add this dummy to the rear seat for its full frontal and frontal offset crash test protocols.

Timing of introduction of vehicle safety initiatives

The table in Appendix 2 gives a timeline for introduction of various vehicle safety initiatives, such as the frontal offset crash test. This illustrates that NCAPs frequently introduce new requirements well ahead of the regulations and, in many cases, sets tougher requirements than subsequent regulations.

These demanding NCAP tests are likely to have been a key factor in the improvements to occupant protection evident over the twelve years analysed for this paper.

CONCLUSIONS

Analysis of vehicle deformation and front occupant injury trends for NCAP frontal offset crash tests conducted between 1996 and 2008 indicated a gradual reduction in the risk of serious head and thorax injury and a strong reduction in the risk of serious lower leg injury.

NCAP programs have likely had an influence on the models that did not perform well and many of these have dropped out of the Australasian market.

Now that there is an ample choice in most vehicle segments, fleet purchasers are increasingly demanding a minimum 4 star ANCAP performance and this appears to have triggered some manufacturers into taking more notice of the ANCAP ratings. There have even been cases of retests of improved models in order to gain a better rating.

Concerns remain about the dismal offset crash performance of many models of commercial vehicle. NCAPs should focus more attention on testing this group and draw attention to the large differences in performance.

There are also concerns about the protection of rear seat occupants and it is clear that most rear seat restraint systems are not keeping pace with the design of front seat restraints. NCAPs should consider adding a small adult female dummy to the rear seat for the offset crash test.

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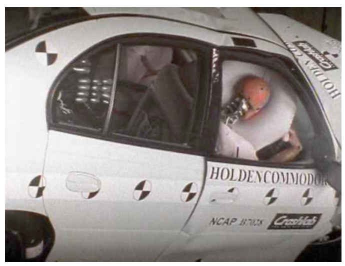
APPENDIX 1 - IMAGES FROM CRASH TEST VIDEOS

The following images illustrate the improvements in structural performance evident from 12 years of ANCAP offset crash tests. ANCAP began the Euro NCAP-style star rating in 1999.

Year Model	Holden Commodore	Ford Falcon
1994-6		
1997-8		
2000 ★★★☆☆		
2003 ★★★★☆		
2008 ★★★★★		

Commercial utility vehicles - 64km/h offset crash tests conducted by ANCAP

Vehicle Model	1995	2005-8
Holden Rodeo		
Mazda Bravo/ BT50 & Ford Courier		
Mitsubishi Triton		
Toyota Hilux		

APPENDIX 2 - TIMING OF INTRODUCTION OF ROAD USER PROTECTION INITIATIVES

Table A2. Timing of Road User Protection Initiatives

Test Procedure	Procedures Developed	Consumer Tests	Regulation (cars)
Full frontal crash test	USA: late 70s	US NCAP: 1979 ANCAP: 1992 (56 km/h)	FMVSS 208: late 1970s (*48km/h*) FMVSS 2008: 2007 (56km/h) ADR 69/00 1995 (*48km/h*)
Offset crash test (40% frontal)	EEVC: early 90s	ANCAP: 1993 (60km/h) IIHS: 1995 (64km/h) ANCAP 1995 (64km/h) EuroNCAP: 1996 (64km/h)	ECE R94: 1998 (*56km/h*) ADR73/00: 2000 for new models, 2004 for existing models (*56km/h*)
Side Impact (Moving barrier, perpendicular impact)	EEVC: early 90s	EuroNCAP: 1996 (50km/h) ANCAP: 1999 (50km/h)	ECE R95: 1998 (50km/h) ADR72/00: 2000 for new models, 2004 for existing models (50km/h)
Side Pole Impact (29km/h perpendicular or 32km/h oblique)	EEVC: mid 90s	Euro NCAP: 1999 ANCAP: 2000 US NCAP: 2010	US FMVSS 214: 2010 ECE ? ADRs ?
Pedestrian Protection	EEVC: early 90s	EuroNCAP 1996 (40km/h) ANCAP: 2000 (40km/h)	ECE 2005 (first phase) ECE 2010 (second phase) ADRs ?

BENEFIT ESTIMATION OF THE EURO NCAP PEDESTRIAN RATING CONCERNING REAL WORLD PEDESTRIAN SAFETY

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Paper Number 09-0387

ABSTRACT

In 2009, Euro NCAP intends to change its rating system. The new rating will put a greater emphasis on the pedestrian protection potential. Therefore, Euro NCAP endeavours to assess the vehicle's overall safety performance and communicate it simply to consumers using a single star rating.

This study aims to estimate, how well the pedestrian rating system matches the expected real-world benefit. Furthermore, the benefit range achieved for different Euro NCAP pedestrian protection scores is determined. The vehicle impact zones and their related NCAP points are also evaluated for their actual effectiveness.

The analysis bases on the German In-depth Accident Study (GIDAS) database. A case-by-case analysis was carried out for 667 frontal pedestrian accidents where the vehicle speed was 40kph or less. More than 500 AIS2+ injuries are analysed regarding severity, affected body region, impact point on the vehicle, and the particular NCAP zone. An injury shift method was then used to determine the benefit derived from each testing zone.

One result of the study is a detailed impact distribution for AIS2+ injuries across the vehicle front. The rating colour code distributions for different vehicles with various higher point levels were compared to the original dataset and to the current standard in pedestrian protection. In order to estimate the overall benefit range, the analyses used optimistic and pessimistic approaches.

It is shown that current vehicles already exhibit significant real-world benefits. Furthermore, the additional benefit for vehicles achieving various point scores were estimated although the calculated benefits are mostly over-estimations due to missing test results for older vehicles and conservative assumptions.

This is the first detailed analysis of injury causation in NCAP zones and has been made possible by high accident numbers. Thus, the expected real-world benefits of any vehicles can be compared to their Euro NCAP test results.

INTRODUCTION

The present study deals with frontal pedestrian accidents under participation of M1 vehicles and collision speeds up to 40 kph. Basing on in-depth accident data, a detailed distribution of pedestrian impact points in Euro NCAP test zones is created. The data is then used for the evaluation of the Euro NCAP pedestrian rating method. Furthermore, the expected real-world benefit of different Euro NCAP colour distributions is estimated.

DATASET

This chapter deals with the data source which is used for the analysis. The sample criteria as well as the creation of the master-dataset are described. To get an overview of the pedestrian accident scenarios some statistical information is provided.

Data source

For the present study accident data from GIDAS (German In-Depth Accident Study) is used. GIDAS is the largest in-depth accident study in Germany. The data collected in the GIDAS project is very extensive, and serves as a basis of knowledge for different groups of interest.

Due to a well defined sampling plan, representativeness with respect to the federal statistics is also guaranteed. Since mid 1999, the GIDAS project has collected on-scene accident cases in the areas of Hanover and Dresden. GIDAS collects data from accidents of all kinds. Due to the on-scene investigation and the full reconstruction of each accident, it gives a comprehensive view on the individual accident sequences and the accident causation.

The project is funded by the Federal Highway Research Institute (BASt) and the German Research Association for Automotive Technology (FAT), a department of the VDA (German Association of the Automotive Industry). Use of the data is restricted to the participants of the project. However, to allow interested parties the direct use of the GIDAS data, several models of participation exist. Further information can be found at http://www.gidas.org.

Sample criteria and master-dataset

The study is carried out on the basis of the current GIDAS dataset, effective July 2008. Out of all 17052 cases in the database only the 13653 reconstructed accidents are used as only these do include information regarding the collision speed.

For the creation of the master-dataset only accidents with at least one involved pedestrian are chosen. Only the first pedestrian hit by the vehicle is considered in the few cases with two or more pedestrians. Taking all reconstructed accidents with a collision of a vehicle and a pedestrian into account 1821 cases can be found in the dataset.

The first sample criterion is the vehicle class. The study considers all accidents with passenger cars of the M1 type (according to the UN-ECE definition). Out of all 1821 pedestrian accidents, 1284 accidents meet this condition, making up 70,5%.

In the next step, only accidents with a frontal impact of the pedestrian are taken into account. This criterion is defined on the basis of the Collision Deformation Classification (CDC, according to the SAE J224). Furthermore, special types of accidents have been excluded from the analysis. These are accidents, where no "typical" frontal impact occurred, for example:

- run-over accidents, where the pedestrian already laid on the road
- accidents where a pedestrian was crushed between two vehicles
- side-swipe accidents, where the pedestrian was hit by the external mirror but not by any other part of the vehicle front

Using the second digit of the CDC (impacted vehicle side) and filtering for frontal accidents will lead to a number of 856 accidents.

At last, the accidents are grouped by the collision speed. The impactor velocity in Euro NCAP tests and in the test definitions of the Directive 2003/102/EC is 40kph. Above this velocity, there is only a very limited potential for passive safety measures. Furthermore, there are hardly any impacts on the bonnet expected. Thus, a distinction is drawn between accidents with a collision speed up to 40kph and the ones above.

The following figure shows the accident numbers within the two groups and the resulting injury severity distribution (Figure 1).

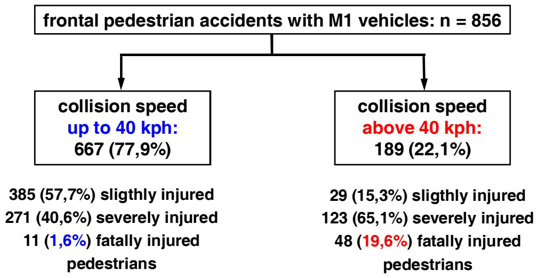

Figure 1. Distinction of accidents with collision speeds up to 40kph and above.

Due to the above mentioned facts, the study considers only accidents with a collision speed of up to 40kph. This leads to the final master-dataset which consists of 667 frontal pedestrian accidents with M1 vehicles and collision speeds up to 40kph. That means, that 36,6% of all pedestrian accidents (667 out of 1821) are principally addressed by legislation and Euro NCAP tests.

Descriptive Statistics

At this point, some information on the master-dataset is given. The distributions of relevant accident parameters as well as some vehicle data and injury severity distributions are displayed to get an overview of the pedestrian accident scenarios.

The accident site and accident scene – are considered first. (Figure 2). More than 98% of all pedestrian accidents in the dataset happened in town. The already large proportion of in-town accidents in the German pedestrian accident scenario (94% in 2006) is thereby further increased by the restriction to accidents with collision speeds up to 40kph within the present study.

Looking at the distribution of accident scenes, it can be seen that more than half of all pedestrians are hit by the car while crossing a straight road. Another 38% collide with the car on crossings and T-junctions. These are mostly accidents where the vehicle turns off to the left or right side without giving right of way to the pedestrian.

The collision speed – is one of the most important parameter in frontal pedestrian accidents, due to the large influence on the injury severity outcome of the pedestrian. As mentioned above, the study deals with frontal pedestrian accidents with collision speeds up to 40kph. The following chart shows the distribution of the collision speed for all accidents in the master-dataset (Figure 2).

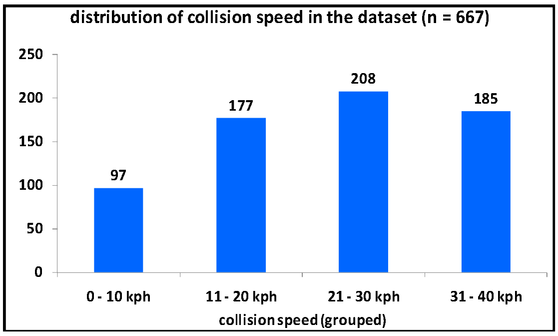

Figure 2. Distribution of collision speed.

The vehicle age – is closely linked to the shape of the vehicle front because the steady development progress as well as the statutory provisions always influences the design of vehicles. It is well known that the front shape is decisive for the pedestrian kinematics and injury causation in case of a frontal impact. The front design of passenger cars changes over time and thus, it is important for the benefit estimation to know how old the vehicles in the dataset are. Thus, the year of market introduction is considered for all vehicles (Figure 3).

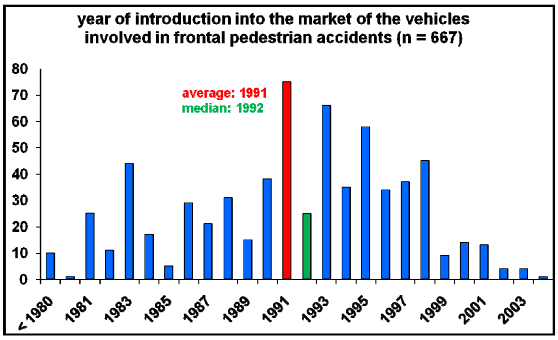

Figure 3. Year of market introduction of the 667 vehicles in the master-dataset.

It can be seen that from today's point of view, the vehicles are rather old. Considering the respective day of the accident for each case, the vehicle age is 11,3 years on average. Furthermore, only few modern vehicles can be found in the dataset due to their small market penetration.

The vehicle age should be considered during the benefit estimation because most of the vehicles did not have to comply with the current legislation concerning pedestrian protection. The vehicles in the dataset do not completely reflect the current vehicle fleet and most of them did not benefit from recently achieved progresses in pedestrian safety.

The age of the involved pedestrians – has a large influence on the injury severity outcome, beside the collision speed and the impacted part of the vehicle. Due to the human physiological properties, elderly people often sustain worse injuries than younger people. Otherwise, children are often hit by other vehicle parts than adults, due to their smaller body height. Especially the head impact areas of children differ substantially from the impact zones of adults.

In the following graph, the age distribution of the pedestrians in the master-dataset is compared to the distribution within the German pedestrian accident scenario of the year 2006 (Figure 4).

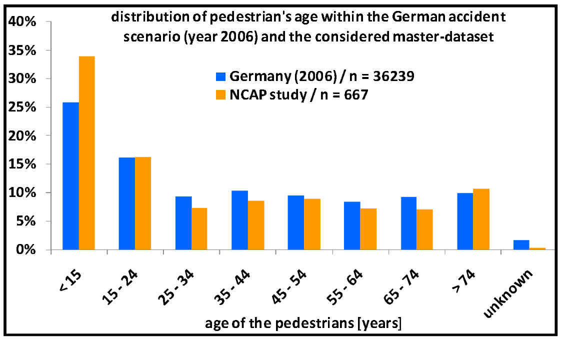

Figure 4. Distribution of the age of the involved pedestrians (master-dataset vs. Germany).

There are some small differences between the distributions, especially in the proportion of children. It has to be considered that the master-dataset only consists of frontal pedestrian accidents with M1 vehicles, whereas the German accident scenario includes all types of pedestrian accidents. This may result in small variations within the distribution. However, the number of involved children (226 persons below 15 years) seems to be sufficient for an estimation of the child head test.

Injury data – are coded in the GIDAS database for every single injury. Pedestrians mostly suffer different injuries. Looking at all injuries in the 667 accidents, 2045 single injuries can be found in the master-dataset. As shown in Figure 6, the majority of these injuries are slight injuries (AIS1). Severe injuries, defined as AIS2 to AIS6 injuries, make up 25,4%. There are 519 AIS2+ injuries in the dataset which will be used for the benefit estimation.

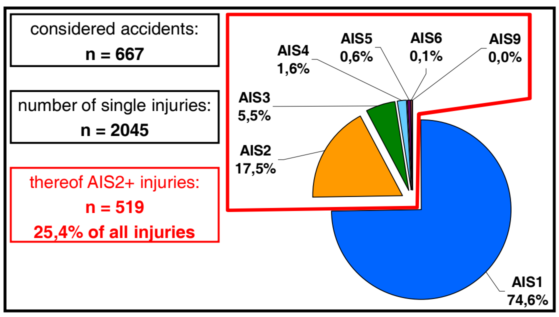

Figure 5. Distribution of injury severity in the master-dataset (n=2045 single injuries).

METHODOLOGY

This chapter describes the methods used in the study. Furthermore, all definitions as well as the assumptions made for the analysis are explained.

Estimation of the Euro NCAP test zones

For the intended benefit estimation of the Euro NCAP test procedures it is necessary to evaluate every single Euro NCAP test zone. For this purpose, the 60 single Euro NCAP test zones have to be determined individually for every single vehicle model. After that, every actually sustained injury in the 667 real-world accidents can be allocated to a particular Euro NCAP test zone if it occurred in such an area.

The determination of the test zones is done on the basis of CAD models, according to the Euro NCAP testing protocol. Due to the different shapes, bonnet lengths and heights, every single vehicle model has to be measured.

The head impact zones – are determined exactly according to the Euro NCAP testing protocol. There are 24 test zones for the child headform test and 24 test zones for the adult headform test. There are four longitudinal rows (two child headform test rows and two adult headform test rows), which are defined by different Wrap Around Distances (WAD). The lateral borders are the Side Reference Lines. Between these two Side Reference Lines, the rows are divided into 12 equal width areas which finally lead to 48 head impact zones.

The resulting grid of testing zones is shown in Figure 6. The example vehicle is taken from a real-world accident out of the master-dataset and is hereafter used for the explanation of the method.

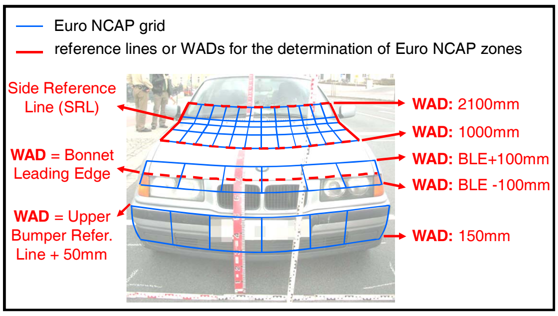

Figure 6. Distribution of injury severity in the master-dataset (n=2045 single injuries).

The upper leg test zones – are primarily defined by the Bonnet Leading Edge Reference Line (BLERL) which is determined according to the Euro NCAP testing protocol. Basically, the vehicle is laterally divided into six equal test zones. For the determination of the longitudinal boundaries, the WAD is used.
In the study, all injuries are considered to be in the upper leg test zone when they have a WAD of ±100mm around the BLE, as shown in Figure 6.

The lower leg test zones – are also determined according to the Euro NCAP testing protocol. The impact zones of the lower legform test are determined by the Upper Bumper Reference Line. Again, the vehicle is laterally divided into six equal test zones. In the study, the lower boundary of the test zones is determined for every vehicle model by the constant WAD value of 150mm. The upper boundary is defined as the Upper Bumper Reference Line plus 50mm (see Figure 6).

Case-by-case analysis

Prior to the benefit estimation, a detailed case-by-case analysis is done for every accident, using a variety of different variables. The aim is the merging of impact data and injury data. The steps of the case-by-case analysis are again illustrated on the basis of the shown real-world accident.

At first, detailed injury information is extracted from the GIDAS database. The following variables, encoded for every single injury, are used:

- injury description (name)
- type of injury (fracture, contusion etc.)
- entire AIS code, including the severity value (AIS1 to AIS6)
- injury location (exact body region)
- injury causing part

As shown in Figure 8, the pedestrian in the example case sustained four injuries. The worst of them, a complicated tibia fracture, leads to the resulting injury severity of MAIS3, which is the maximum AIS value of all single injuries.

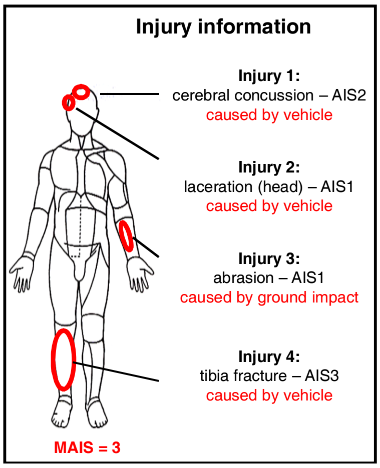

Figure 7. Injury information (example case).

In addition to the medical information, a lot of vehicle data and impact data are investigated at the accident scene for every accident. Chiefly, the impact points on the vehicle are important for the injury causation and the reconstruction. Therefore, every impact point is measured exactly and can thus be described by its WAD (using a measuring tape, see Figure 8) and the lateral distance from the vehicle's longitudinal axis (y-value).

The following illustration shows the collision partner in the example case, a BMW 3-series (E36). The three impact points, which could be found at the vehicle, are marked with blue arrows. The relevant WAD and y-values are listed beside.

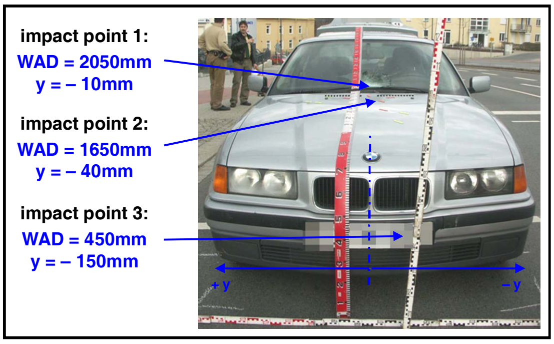

Figure 8. Involved vehicle and documented impact points (example case).

In the next step, injury data and vehicle/impact data are merged. Every single injury that occurred on the vehicle is allocated to an impact point.

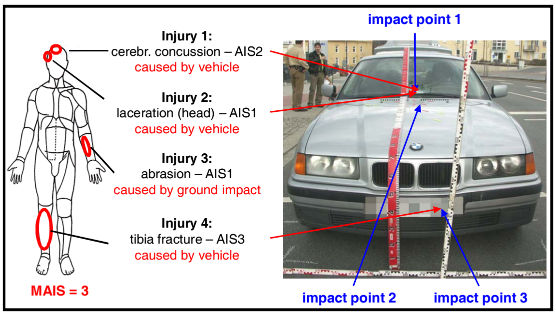

Figure 9. Allocation of single injuries and impact points (example case).

As illustrated in Figure 9, the two head injuries in the example case can be allocated to the impact point 1. The third injury was caused by the ground impact. It is therefore not assignable to an impact point on the vehicle. The fourth injury is allocated to the impact point 3 at the bumper. It can be seen, that an impact point at the vehicle must not necessarily lead to an injury. Impact point 2, for instance, results from an impact of the shoulder, even though the pedestrian did not sustain any injuries in this body region.

In the next step the injuries are allocated to the Euro NCAP test zones. As described above, the 60 test zones are determined separately for every vehicle model, using WAD and y-values. As seen, all single injuries have been allocated to an impact point and thus, they also have individual WAD and y-values now. Hence, every single injury can be assigned to a Euro NCAP test zone.

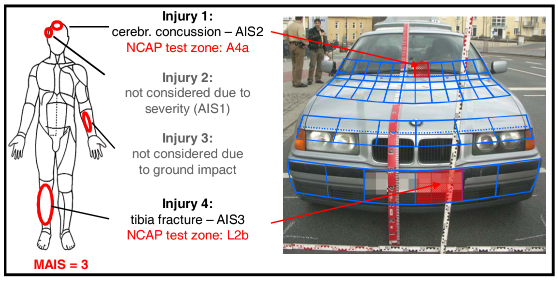

Figure 10. Allocation of single injuries to the Euro NCAP test zones (example case).

As mentioned, only AIS2+ injuries are considered for the analysis. According to this restriction, the pedestrian in the example case sustained two severe injuries in a Euro NCAP test zone (Figure 10). The first injury (AIS2) occurred in the adult head test zone A4a. The second injury is not considered due to its severity (AIS1). The third injury was caused by the ground and thus, it can not be allocated to a Euro NCAP test zone. Finally, the fourth injury (AIS3) was caused by the bumper, within the Euro NCAP test zone L2b (lower leg).

This method is used for all 667 accidents. As a result, all 519 AIS2+ injuries in these accidents can be either allocated to a Euro NCAP test zone or to another vehicle zone or to the ground impacts. The consequent distribution is shown later.

Optimistic and pessimistic approach

Over time, several studies concerning the evaluation of passive pedestrian safety measures have been carried out. The underlying number of injuries which are used for the benefit estimation is often the decisive point. There are two different possibilities to evaluate passive safety measures.

The first approach uses all injuries which are sustained in all test areas. For example child head injuries are also regarded if they are caused by the bonnet leading edge, although this vehicle part is essentially addressed by tests concerning upper leg and pelvis injuries. By using this approach it is assumed that all injuries in all body regions will benefit from passive safety measures. For this reason the approach is called optimistic approach. This method probably overestimates the benefit of passive safety measures.

In contrast, the pessimistic approach only uses injuries which are sustained in addressed areas of the vehicle. That means that only injuries are considered in the three body regions which are addressed by Euro NCAP tests: head, lower leg and upper leg/pelvis. Consequently, all injuries to the upper extremities, thorax, abdomen and spine are left out. So, the above mentioned child head injury, which was caused by the bonnet leading edge, is not considered within this approach.

However, it can be expected that an optimised impact zone will even have a positive effect on injuries in other body regions. An optimised head impact zone on the bonnet, for instance, could mitigate injuries to the thorax or abdomen, too. Thus, the pessimistic approach underestimates the benefit of passive safety measures.

It is difficult to decide which of the two approaches is more realistic. Hence, the study uses both approaches in order to estimate the benefit range. The actual benefit lies somewhere between.

Injury Shift Method

For the intended evaluation of the Euro NCAP pedestrian rating method and the benefit calculation of different rating results, the performance of particular Euro NCAP test zones has to be estimated. Due to the fact, that real-world accident databases do not contain any information about the Euro NCAP testing parameters like HIC, bending moment, knee bending angle, leg impact force and lower leg acceleration, the evaluation cannot directly take place on the basis of these physical parameters. For this reason, the Euro NCAP test zones are estimated on the basis of their colour, representing these parameters.

Within the Euro NCAP pedestrian rating, all 60 test zones are judged on the basis of physical parameters. Afterwards, a characteristic colour is assigned to every test zone, namely green for a good pedestrian protection, yellow for an adequate pedestrian protection and red for a marginal one.

This colour code can be used for the estimation of effectiveness of single test zones. It is assumed that the original severity of an injury could be reduced by a green or yellow test zone. That means the AIS value is shifted downwards if the injury was sustained in a Euro NCAP zone which is coloured green or yellow within the present distribution. This method is called injury shift. The extent of the injury severity reduction depends on the colour of the particular test zone which should be evaluated. As shown in Figure 11, it is assumed that the injury severity in a green Euro NCAP test zone decreases stronger than in a yellow one.

Injuries in red Euro NCAP test zones are neither shifted within the optimistic approach nor in the pessimistic one. It is assumed that red test zones will have no injury reduction potential. Generally, the severity of an injury can be shifted towards AIS1 at the maximum. It is assumed that no injury is entirely avoided (AIS0).

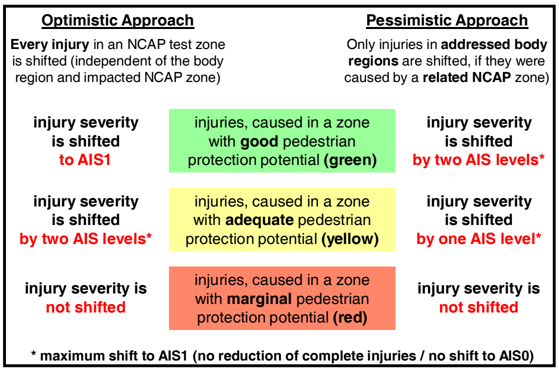

Figure 11. Assumptions (Injury shift method).

The injury shift method considers the idea of using an optimistic and a pessimistic approach. As seen in Figure 11, the injury severity shift is bigger within the optimistic approach which finally leads to a greater benefit. Within the pessimistic approach, the injury severity shift is done more conservatively.

The methodology of the injury shift method is explained on the basis of an example within the following chapter.

Benefit estimation

For every real-world accident in the dataset it is known which injuries the pedestrian has sustained and which impact zones were responsible for them. Along with the measured Euro NCAP test zones for every vehicle model it is now possible to evaluate any Euro NCAP colour distribution regarding its actual real-world benefit. In Figure 12, an example for such a colour distribution (left side) as it may result from a Euro NCAP rating test is shown.

This colour distribution is then assumed for all vehicles in the dataset. Using the injury shift method, it is calculated how the injury severity outcome will be if all M1 vehicles in pedestrian accidents would have this Euro NCAP distribution. For this purpose, an assumption has to be made concerning the original pedestrian safety performance of the vehicles in the dataset.

Basically, it is assumed that all vehicles in the GIDAS dataset will solely have red test zones which corresponds to zero Euro NCAP points (see right picture in Figure 12).

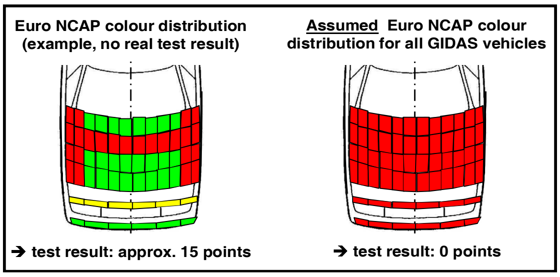

Figure 12. Euro NCAP colour distribution (example) / Assumed GIDAS distribution.

Due to the fact that the vehicles in the GIDAS dataset are rather old, this assumption seems to be suitable. Unfortunately, the actual pedestrian protection performance is unknown for the majority of the vehicles, due to missing Euro NCAP test results. However, especially in windscreen and bonnet test zones a better performance is realistic even for older vehicles. Hence, this assumption is very conservative and leads in any case to an overestimation of the benefit.

Keeping this in mind, the benefit is calculated. As described, the severity of all AIS2+ injuries in green or yellow test zones is shifted downwards according to the assumptions in Figure 11. Then, the injury severity (represented by the MAIS) is re-calculated, resulting from the maximum AIS value of all injuries. Depending on the number, the severity and the causation of the injuries, the MAIS of a pedestrian is reduced or remains constant.

The following illustration shows the methodology in an example (Figure 13). On the basis of the example accident, two different Euro NCAP colour distributions are evaluated (pessimistic approach). The distributions are chosen in a way to show different resulting MAIS values for the pedestrian.

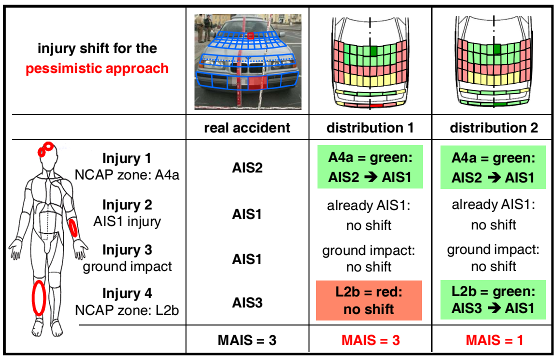

Figure 13. Evaluation of Euro NCAP colour distributions (injury shift method).

As seen above, the pedestrian in the real-world accident suffered two AIS2+ injuries in Euro NCAP test zones. His injury severity is MAIS3, resulting from his tibia injury.

Now, the two different Euro NCAP colour distributions are assumed for the accident vehicle. According to the colour in the test zones A4a and L2b, the injury severity is either shifted (green or yellow zone) or remains unchanged (red zone). As a result, the pedestrian will have a re-calculated injury severity of MAIS3 or MAIS1.

This procedure is done for all 667 pedestrians. The overall benefit of a Euro NCAP colour distribution is then calculated. Thereby, the benefit is defined as the number of reduced MAIS2+ injured pedestrians. In the above given example, only the second distribution (rightmost column) will achieve a reduction from MAIS2+ injured MAIS1 injured.

ANALYSES AND RESULTS

This chapter contains information about the single steps of the analysis and the related results. At first, the detailed impact distributions are considered. Afterwards, the estimation of different Euro NCAP rating results is done.

Impact distribution

At first, the results of the case-by-case analysis are presented. As described above, all AIS2+ injuries are either allocated to a Euro NCAP test zone or to another (non-tested) vehicle zone or to the ground impact. Using this data, a detailed analysis concerning single Euro NCAP test zones is done.

<u>The optimistic approach</u> – uses all injuries of the pedestrian, independent from the body region. For this reason, all injuries in Euro NCAP test zones are considered for the impact distribution. Figure 14 gives an overview of the general impact location for the 519 AIS2+ injuries in the dataset.

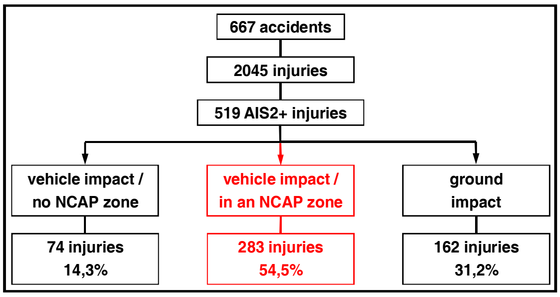

Figure 14. Type (location) of impacts (AIS2+ injuries, optimistic approach).

It can be derived from the diagram that about 55% of all AIS2+ injuries were sustained in Euro NCAP test zones. Nearly one third of the injuries were caused by the ground impact and the remaining 14% occurred in non-tested vehicle areas.

In the next step, a detailed distribution is generated for all 60 Euro NCAP test zones. As seen in Figure 15, two of the considered injuries result from the example case. Thus, they are recorded in their specific test zones as shown in Figure 15.

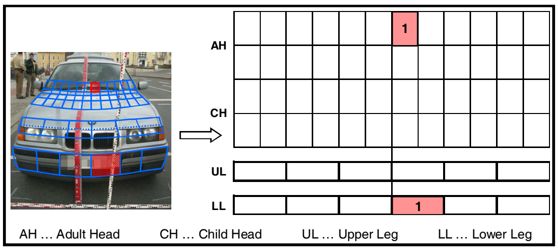

Figure 15. Transfer of impact zones (example).

This procedure is repeated for all 667 accidents respectively for the 283 AIS2+ injuries that occurred in Euro NCAP test zones. The number of impacts in every test zone is added and finally, the following distribution can be derived (Figure 16).

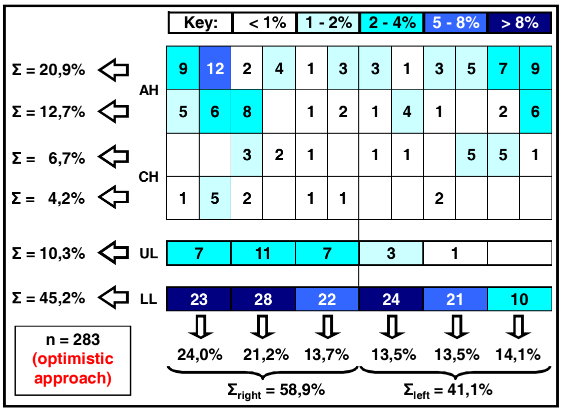

Figure 16. Distribution of impact zones (AIS2+ injuries, optimistic approach).

In addition to the absolute number of impacts, the frequencies are illustrated by a colour scale. Furthermore, the proportions of single test rows and within the six vertical columns are displayed.

It can be seen that the pedestrian impacts, which caused AIS2+ injuries, are not symmetrically distributed. The majority (59%) of the pedestrians are hit by the right side of the vehicle which seems to be a result of the right-hand traffic in Germany. Nearly one quarter of the impacts are located rightmost on the vehicle front. The frequency in the rightmost lower leg test zone is more than twice as high as the frequency in the leftmost zone.

Considering the single test rows, it can be stated that approximately half of all AIS2+ injuries (45%) occur in the lower leg test zone. This area is by far the most frequent injury causing area for AIS2+ injuries on the vehicle.

Another third of the impact points is located within the adult head test zones and 11% are found in the child head test area. Impacts in the upper leg test row make up about 10%. It has to be considered that the comparably high numbers of AIS2+ injuries in this zone result from the high proportion of old vehicles in the dataset. These vehicles often have sharp-edged bonnet leading edges and thus, they caused severe injuries in this test area. However, the number of such injuries decreases in accidents with younger vehicles. Not more than three out of the 29 injuries in the upper leg area were caused by vehicles introduced 1997 or later.

<u>The pessimistic approach</u> – only bases on injuries within the three addressed body regions. As shown in Figure 17, the 283 AIS2+ injuries in Euro NCAP test zones are separated into two groups. Out of all injuries in Euro NCAP test zones, one quarter (71 of 283) is not directly addressed by the specific tests. However, 212 AIS2+ injuries remain for the analysis of impact distribution, representing 41% of all AIS2+ injuries in the dataset.

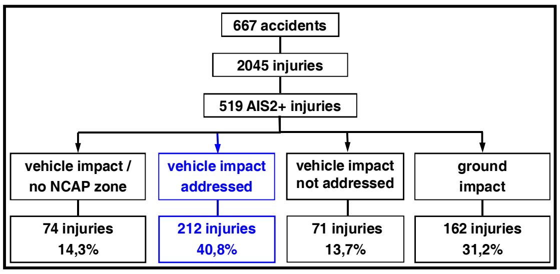

Figure 17. Type (location) of impacts (AIS2+ injuries, pessimistic approach).

The impact zones of the relevant AIS2+ injuries are summed up for all 667 accidents which finally lead to the distribution shown in Figure 18. Again, an asymmetrical distribution can be derived from the data. About 60% of the impact points were located in Euro NCAP test zones on the right vehicle side.

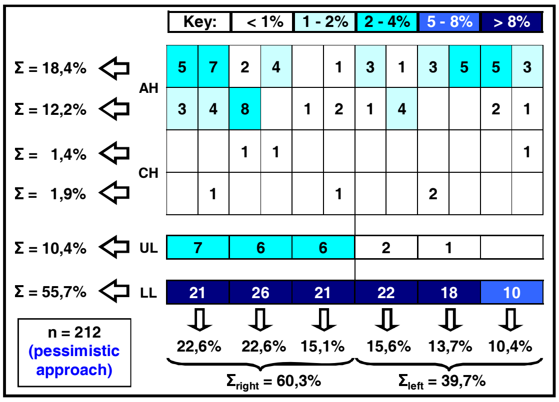

Figure 18. Type (location) of impacts (AIS2+ injuries, pessimistic approach).

In comparison to the results of the optimistic approach, the proportion of impacts in the lower leg test zones increases further to more than 55%. The proportion of impacts in the adult head test zone decreases slightly to 31% whilst the proportion of head impacts in the child head test zone decreases substantially to not more than 3,3%. This implies that this test zone hardly causes severe head injuries but injuries to other body regions, like thorax, abdomen or upper extremities. The proportion of impacts in the upper leg test zones remains constant. Again, the majority of these injuries results from accidents with older vehicles. Two out of the 22 injuries in this zone were caused by vehicles introduced in 1997 or later.

Evaluation of the Euro NCAP pedestrian rating

Using the results of the case-by-case analysis and the detailed impact distribution, various analyses can be carried out with the available data. Two of them are shown hereafter.

At first, the general potential of passive safety measures concerning the Euro NCAP tests is given. Principally, all passenger cars are addressed by the Euro NCAP tests. The test procedures are meant for frontal collisions and, as mentioned above, the potential of passive safety measures is limited to certain collisions speeds. For this reason, the filter criteria for the present study were determined according to these facts.

The following overview, including the numbers of MAIS2+ injured pedestrians, is given to illustrate the possible benefit for the entire pedestrian accident scenario.

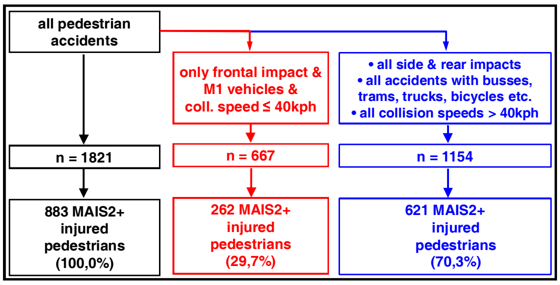

Figure 19. Relevance of accidents addressed by the Euro NCAP pedestrian rating.

It can be derived from the figure, that not more than 30% of all MAIS2+ injured pedestrians are involved in the considered frontal accidents with M1 vehicles and collision speeds up to 40 kph. For this reason, the benefit of passive safety measures in Euro NCAP test zones is generally limited. For the intended analyses, 262 MAIS2+ injured pedestrians are available in the 667 accidents.

The first analysis deals with the allocation of points to the single test zones and the benefit of single areas. The analysis should answer the question, which benefit for the real accident scenario can be expected from the optimisation of single test zones and how the Euro NCAP rating method does factor in the real-world injury causation. For this purpose, seven idealised Euro NCAP colour distributions are generated. Then, their real-world benefit is estimated and compared to the related Euro NCAP rating result. Figure 20 shows the seven colour distributions and their Euro NCAP point scores.

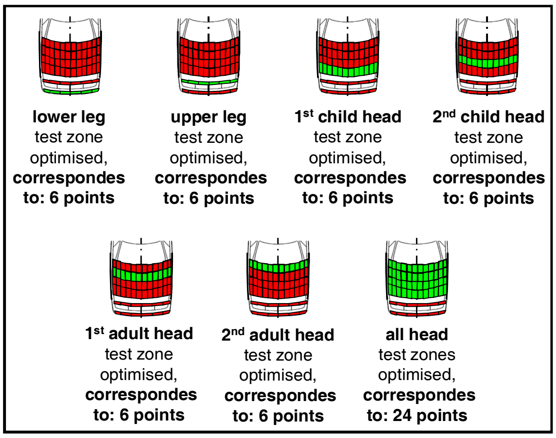

Figure 20. Idealised Euro NCAP shapes.

There are six distributions with one optimised (i.e. green) test row (each corresponding to six Euro NCAP points) and another distribution, where all head impact test zones are optimised (resulting in 24 Euro NCAP points).

Every distribution is then assumed for all vehicles in the dataset and the resulting number of MAIS2+ injured pedestrians is calculated. Using the optimistic as well as the pessimistic approach, the benefit range can be estimated, too. The following graph shows the calculated reduction of MAIS2+ injured pedestrians for the seven idealised Euro NCAP colour distributions.

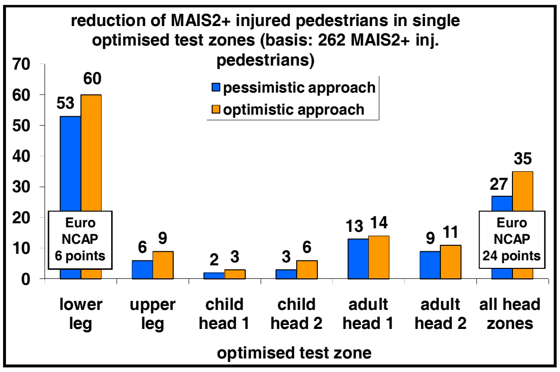

Figure 21. Reduction of MAIS2+ injured pedestrians by single optimised test zones.

Due to its high number of impacts, an optimised lower leg test area will have the greatest benefit, considering the reduction of MAIS2+ injured pedestrians. As illustrated, an optimised lower leg area, which achieves six Euro NCAP points, can save between 53 and 60 pedestrians from being MAIS2+ injured whilst an optimised head impact test area (achieving 24 Euro NCAP points) will save between 27 and 35 of these pedestrians. From this point of view the lower leg test zones seems to be underestimated towards the head impact zones within the Euro NCAP pedestrian rating.

In conclusion, a higher Euro NCAP result is not always linked to a higher benefit. A several times higher Euro NCAP point score must not necessarily be as effective as single optimised test zones.

Benefit estimation of various Euro NCAP point scores

The second analysis deals with the question, which benefit range can be expected from increasing the average pedestrian protection level by six Euro NCAP points. Furthermore, it is estimated how large the benefit range can be between different vehicles achieving the same number of Euro NCAP points. For the study, two Euro NCAP colour distributions achieving 18 points as well as two colour distributions achieving 24 points are generated. The latest Euro NCAP tests show, that these point scores are realistic for currently developed and recently testes vehicles.

On the one hand, the real-world impact distribution is used as a basis for the creation of one "good" and one "bad" Euro NCAP colour distribution. On the other hand, the distributions are generated with regard to current Euro NCAP test results. Thus, nearly all distributions already have green lower leg areas, although they have the greatest effect on the calculated benefit. If one would additionally look for colour distributions with red lower leg areas on purpose, even more wide-spread results could be achieved. In addition, nearly all of the outermost test zones in the head impact areas (near the Side Reference Lines) are coloured red which represents the current technical feasibility.

The used distributions are shown in Figure 22.

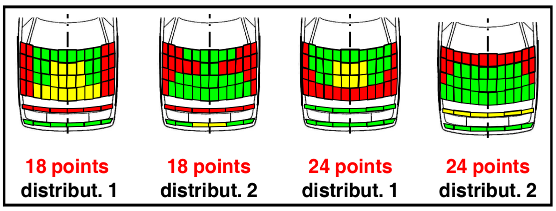

Figure 22. Euro NCAP colour distributions for the estimation of 18 and 24 points vehicles.

The benefits of the four colour distributions are estimated, assuming again that all 667 vehicles in the dataset have the same colour distribution. Then, the results of the four distributions are compared.

The calculated numbers of MAIS2+ injured pedestrians are shown in the following table.

Table 1.
Reduction of MAIS2+ injured pedestrians for the estimated 18 and 24 points vehicles

	NUMBER of MAIS2+ injured pedestrians		**REDUCTION** of MAIS2+ injured pedestrians
	pessi-mistic appr.	**opti-mistic appr.**	**benefit**
basis (master-dataset)	262		---
18 points distribut. 1	**172**	**171**	**90 … 91**
18 points distribut. 2	**188**	**181**	**74 … 81**
24 points distribut. 1	**162**	**158**	**100 … 104**
24 points distribut. 2	**178**	**177**	**84 … 85**

Looking at the 18 points vehicles, it can be derived from the table that the number of reduced MAIS2+ injured pedestrians already differs between the two distributions. The first distribution reduces the number of MAIS2+ injured pedestrians by 74 (pessimistic approach) respectively 81 (optimistic approach) persons. The second distribution leads to a reduction of 90 (91) severely injured pedestrians. The range within the group of 18 points vehicles amounts 10 (16) MAIS2+ injured pedestrians, representing 12,3% for the optimistic approach and even 21,6% within the pessimistic approach.

Similar results can be derived from the two distributions reaching 24 points. The first one will reduce the number of MAIS2+ injured pedestrians by 100 (pessimistic approach) respectively 104 (optimistic approach) persons. The second distribution leads to a reduction of 84 (85) MAIS2+ injured pedestrians. The range between both 24 points distributions again reaches considerably high values of 16 respectively 19 persons, which are 19,0% for the pessimistic approach and 22,4% for the optimistic one.

Figure 23 illustrates the calculated benefit ranges, separated by the two approaches. Every bar is built by the results of the two distributions with the same Euro NCAP point score.

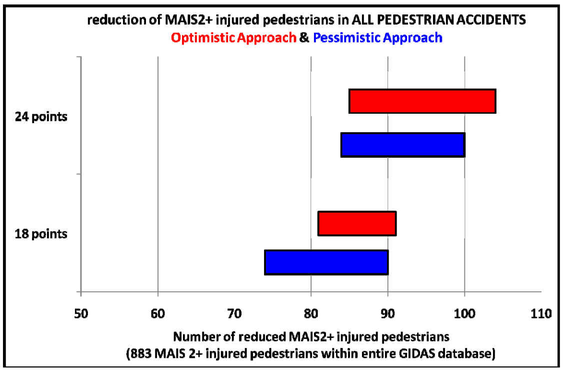

Figure 23. Comparison of calculated benefits (reduction of MAIS2+ injured pedestrians) of 18 and 24 points Euro NCAP colour distributions.

The benefit of the bad 24 points distribution is smaller than the benefit of the good 18 points one. The benefit range within one NCAP level may be greater than the difference between two levels that are six points apart from each other. Comparing the two good distributions with each other as well as the two bad ones with each other shows that the 24 points vehicles will finally have higher benefits.

RESTRICTIONS OF THE STUDY

As mentioned, not all vehicles will actually achieve zero Euro NCAP points. Unfortunately, only ten vehicles (in 667 accidents) have already been tested by Euro NCAP. In these ten accidents, one AIS2 injury is still found that was caused by a green Euro NCAP zone. Thus, the assumption, which says that a green test zone does not cause AIS2+ injuries, is not entirely exact. Furthermore, the assumption that all GIDAS vehicles have zero Euro NCAP points, leads to an over-estimation of the absolute benefit.

Another fact is the use of the Abbreviated Injury Scale (AIS). The process of the injury shift method is not distinguished for different severity levels. An AIS5 injury, for instance, is treated the same way as an AIS2 injury. The severity of both injuries is reduced to AIS1 (optimistic approach) in case of green Euro NCAP test zones. Thus, the maximum injury severity may be reduced to MAIS1 in both cases. However, there is a large difference between an originally MAIS5 injured person and an originally MAIS2 injured one. The effect of the injury severity reduction on the probability of surviving depends substantially on the MAIS level.

SUMMARY AND CONCLUSIONS

The study deals with frontal pedestrian accidents under participation of M1 vehicles and collision speeds up to 40kph. In a case-by-case analysis of 667 accidents, the pedestrian's impact points on the vehicle are measured exactly regarding the WAD and the lateral distance from the vehicle mid. More than 500 AIS2+ injuries are analysed concerning severity, body region and injury causation.

At first, a detailed impact distribution is generated out of the accident data. The front shapes of the involved vehicles are measured and every AIS2+ injury is allocated to the actual Euro NCAP test zone or to other vehicle areas or the ground impact. Nearly half of all AIS2+ injuries occurred in Euro NCAP zones and about one third of the considered injuries were sustained in the ground impact.

Various analyses can be done on the basis of the impact distributions. This study uses the data for the evaluation of the Euro NCAP pedestrian rating and for the benefit estimation of different Euro NCAP colour distributions. Here, the benefit is defined as the reduction of MAIS2+ injured pedestrians, resulting from single injury severity reductions in yellow and green test zones.

At first, some idealised shapes are evaluated to answer the question, which benefit can be expected from the optimisation of single test rows. Finally, it can be stated that an optimised lower leg area could reduce most of the AIS2+ injuries in Euro NCAP test zones, due to the frequent impacts in this zone.

Next, the benefit of different Euro NCAP colour distributions achieving 18 respectively 24 points is estimated. For this purpose, one "good" and one "bad" Euro NCAP colour distribution is generated for each point score and then evaluated concerning the expected real-world benefit. The results show that the benefit range within one Euro NCAP level can be as large as or greater than the difference between an 18 points and 24 points vehicle. This conclusion is derived from the analysis of realistic (feasible) Euro NCAP distributions. Using the real-world impact distribution and disregarding the feasibility, it is even better possible to derive a "most effective" distribution as well as a "hardly effective" one for nearly every Euro NCAP level. The real-world benefit will differ substantially, although the Euro NCAP point score is the same!

Taking the actual real-world impact points as a basis, vehicles with different Euro NCAP colour distributions will achieve different real-world benefits, depending on the individual position of their red, yellow and green fields. Vehicles with equal Euro NCAP pedestrian ratings (point scores) may have great as well as small real-world benefits.

The results of the study show that it is highly recommended to include findings out of real-world accident data and associated effectiveness studies in the development of passive safety measures, legislation tests or ratings like Euro NCAP.

DRIVER ALCOHOL DETECTION SYSTEM FOR SAFETY (DADSS) – A NON-REGULATORY APPROACH IN THE DEVELOPMENT AND DEPLOYMENT OF VEHICLE SAFETY TECHNOLOGY TO REDUCE ALCOHOL-IMPAIRED DRIVING

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ABSTRACT

While government regulations play an important role in ensuring vehicle safety, voluntary approaches to the design and implementation of vehicle safety systems are increasing in importance as vehicle manufacturers deploy safety systems well in advance of, and even in the absence of, government regulations requiring them. This paper provides an overview of regulatory and non-regulatory approaches to vehicle technology development and deployment, and will describe a new, innovative public\private partnership underway to develop an in-vehicle alcohol detection system. In response to concerns about limited progress in reducing alcohol-impaired driving in the United States during the last decade, attention is focusing on technological approaches to the problem. One strategy includes efforts to increase the application of current breath alcohol ignition interlocks on the vehicles of Driving While Intoxicated (DWI) offenders. However, in recognition that many alcohol-impaired drivers have not been convicted of DWI, an effort is underway to develop advanced in-vehicle technologies that could be fitted in vehicles of all drivers to measure driver blood alcohol concentration non-invasively. The Automotive Coalition for Traffic Safety (ACTS, a group funded by vehicle manufacturers) and the National Highway Traffic Safety Administration (NHTSA) have commenced a 5-year cooperative agreement entitled Driver Alcohol Detection System for Safety (DADSS) to explore the feasibility of, and the public policy challenges associated with, widespread use of in-vehicle alcohol detection technology to prevent alcohol-impaired driving. This paper will outline the approach being taken, and the significant challenges to overcome.

INTRODUCTION

Prior to the mid-1960s, the role of vehicle design in preventing crashes and mitigating crash injuries was not generally considered. The focus at that time was on trying to prevent crashes by changing driver behavior (O'Neill, 2003). However, in 1966, in the aftermath of U.S. Senate hearings on vehicle safety, legislation was enacted that authorized the U.S. Federal Government to set safety standards for new vehicles. The result, in 1967, was the first U.S. Federal Motor Vehicle Safety Standard specifying requirements for seat belt assemblies. A host of other regulations quickly ensued to address vehicle performance in several categories: pre-crash (e.g., tires, brakes, transmissions), crash-phase (e.g., head restraints, front and side impact protection, roof crush, windshields), and post-crash (e.g., fuel system integrity, flammability of interior materials). Shortly thereafter other governments followed suit in implementing similar regulations, for example, in Europe, Australia, and Canada. Most U.S. motor vehicle regulations have been evaluated by the National Highway Traffic Safety Administration (NHTSA) at least once since 1975 (Kahane, 2008). Based on these evaluations, NHTSA estimates that Federal Motor Vehicle Safety Standards have saved 284,069 lives between the time of their inception and 2002 (Kahane, 2004).

Government regulations are important in ensuring that vehicles meet a minimum standard of safety. However, there are many other ways in which vehicle safety can be advanced outside of the regulatory framework.

It was once believed that "safety does not sell". However, that perception has changed as more and more consumer-oriented vehicle assessment crash test programs have proliferated around the world. The aim of consumer crash test programs is to encourage manufacturers to go beyond these minimum requirements incorporated in the regulations.

NHTSA was the first to launch a consumer-oriented crash-test program. Starting in 1978, under the authority of Title II of the Motor Vehicle Information and Cost Savings Act of 1973, NHTSA began assessing the frontal crash protection capabilities of new cars by measuring injury potential in crash tests at speeds higher than those required by law. This program, known as the New Car Assessment Program (NCAP) was expanded in 1983 to include frontal crash protection for light trucks, and again in 1997 with the launch of NCAP tests assessing side impact protection (www.safercar.gov). More recently, in 2001, NHTSA also began adding information about rollover resistance to their NCAP program, and information about the availability of advanced technology is being added with the 2011 model year.

In the last 15 years, consumer crash test programs have been launched in many other countries. In the United States, the Insurance Institute for Highway Safety (IIHS) began providing passenger vehicle crash test ratings in 1995, and now offers information on frontal offset, side, and rear impact protection (http://www.iihs.org/ratings/). European NCAP was launched in 1997, and includes vehicle crash test ratings for frontal, and side impacts, including a pole test to measure head protection, and tests to assess pedestrian protection (http://www.euroncap.com/). The Australian NCAP, in place in Australia and New Zealand, began testing similar to EuroNCAP in 1999 and uses the same rating system (http://www.ancap.com.au/testing/). Japan began its NCAP in 1995, (http://www.nasva.go.jp), Korea initiated crash testing in 1999 (http://www.kotsa.or.kr/main.jsp) and China also now has begun its own NCAP program (http://www.fia.com/oldautomotive/issue4/mobility/article2.html).

The desire to earn good ratings in such programs has driven major improvements in vehicle safety, and they have become de facto standards for much of the automobile industry. NCAP-type programs have resulted in clear improvements in vehicle designs to withstand crash forces, and in significant reductions in dummy injury measures. For example, in 1979, when U.S. NCAP was just beginning, the Head Injury Criterion (HIC), a measure to indicate the likelihood of a serious head injury, was exceeded in 22 of 30 vehicles tested. In contrast, only one of 29 vehicles tested in 1995 exceeded the HIC (Ferguson, 1999).

Comparing the performance of 1995-98 model vehicles with 1999-2001 vehicles, IIHS reported large improvements in vehicle ratings on their frontal-offset crash-test program largely as the result of improvements in vehicle structures (Lund, et al., 2003, see also O'Neill, 2005). Furthermore, these improvements have come about at a faster pace than would have been possible through regulation. There have been a few evaluations that indicate such programs are effective in improving occupant protection in real world crashes. These studies indicate that vehicles that perform better in frontal crash tests result in lower injury risks for their occupants (Farmer, 2005; Kahane, 1994; Newstead et al., 2003). Lie and Tingvall (2002) evaluated European crash test ratings, which are derived from a combination of frontal offset and side impact tests, and demonstrated a correlation with real-world crash injury risk.

In recent years, there have been some clear examples of the automobile industry and government working together to expedite the safety process. The safety marketplace has proven to be a catalyst for innovative technologies and vehicle manufacturers increasingly are deploying safety systems well in advance of, or even in the absence of, government mandates.

Since 1999 frontal airbags have been required in all new passenger vehicles, however, side airbags were introduced without government regulations requiring them. Because early experience indicated that frontal airbags could result in injury or death to occupants who were close to them when they deployed, there were some concerns about the potential of side airbags to injure out-of-position occupants. In May, 1999 the NHTSA Administrator requested that the automobile industry work together to quickly develop test procedures for assessing side airbag safety. The Side Airbag Technical Working Group, sponsored by IIHS, the Alliance of Automobile Manufacturers (the Alliance), the Association of International Automobile

Manufacturers, and the Automotive Occupants Restraints Council, was formed and within 15 months voluntary standards had been developed (http://www.iihs.org/ratings/protocols/default.html). All vehicle manufacturers committed to follow this protocol when designing new side airbag systems and 90 percent of vehicles with side airbags conform to these voluntary guidelines (www.safercar.gov).

Another example of cooperative research to improve vehicle safety is provided by the Blue Ribbon Panel for the Evaluation of Advanced Airbags. The Panel was formed in 2001, amid concerns about possible negative effects of changes in frontal crash-test regulations to reduce the aggressivity of deploying airbags (http://www.brpadvancedairbags.org/). The Panel's independent group of experts oversaw the collection of Alliance-funded frontal crash data, the purpose of which was to hasten and facilitate the understanding of redesigned frontal airbag performance. It was agreed that data collection should utilize the existing National Automotive Sampling System/Crashworthiness Data System program and NHTSA observers took part in all the meetings and provided guidance to the Panel on data collection issues.

In addition, the Panel conducted timely research and sponsored research by others. A 2008 research review undertaken by the Panel concluded that redesigned frontal airbags resulted in far fewer airbag-induced injuries to vulnerable occupants, while at the same time maintaining their overall effectiveness in frontal crashes (Ferguson et al., 2008).

Programs such as these illustrate the benefits of government and industry working together to address important safety concerns. Progress can be accelerated and the end result is better working relationships and programs that are more likely to have widespread acceptance. The latest example of an innovative public/private partnership is the Driver Alcohol Detection System for Safety (DADSS) program which seeks to find a solution to the problem of alcohol-impaired driving.

DADSS - A NEW DEVELOPMENT AND DEMONSTRATION PROGRAM

Background

Alcohol-impaired driving is a major factor in the tens of thousands of deaths that occur every year on U.S. roads. In 2007, there were almost 13,000 fatalities in crashes involving drivers with blood alcohol concentrations (BACs) of 0.08 g/dL or higher – the legal limit in all 50 U.S. States (NHTSA, 2008). This number represented 32 percent of total traffic fatalities for the year. Although significant progress was made during the 1980s and the first half of the 1990s in reducing this problem, since then progress has been limited. Strong laws and enforcement have been effective in reducing deaths and injuries from drinking and driving (Elder et al., 2002; Shults et al., 2001). Such efforts will need to continue; however more must be done if substantial progress is to be made in the long term.

The potential for in-vehicle technology that could prevent alcohol-impaired driving has been recognized. Current aftermarket breath testing devices, in use for several decades, can be installed in vehicles and measure a driver's BAC. These devices predominantly are used by drivers convicted of DWI, and require drivers to provide breath samples before starting their vehicles. If a positive Breath Alcohol Concentration (BrAC) is registered, the vehicle cannot be started. Studies indicate that while these devices are on the vehicles of convicted DWI offenders, they can reduce recidivism by about two-thirds (Willis et al., 2004).

A total of 47 States permit or mandate alcohol ignition interlocks for certain offenders, however, they are generally underutilized. Many lives could be saved if they were more widely applied among the population of DWI offenders. It has been estimated that, if all drivers with at least one alcohol-impaired driving conviction within 3 years prior to the crash were restricted to zero BACs, about 1,100 deaths could have been prevented in 2005 (Lund et al., 2007).

Efforts are underway in the United States to increase the use of breath-alcohol ignition interlocks among convicted DWI offenders, both through passage of stronger state laws that will require them for first-time offenders, and through efforts to work within the criminal justice system to maximize their adoption (http://www.madd.org/Drunk-Driving/Drunk-Driving/Campaign-to-Eliminate-Drunk-Driving.aspx).

Even if such efforts are successful, they would only partially solve the problem of alcohol-impaired drivers. That is because a large proportion of the alcohol-impaired fatal crashes that occur every year involve drivers with no prior DWI convictions. In 2006 only 7 percent of drivers in fatal crashes with BACs 0.08 g/dL or higher had previous alcohol-impaired driving convictions on their records for the prior 3 years (IIHS, 2008).

Wider deployment of current alcohol ignition interlock technology as a preventative measure among the general public is not advisable because of the obtrusive nature of the technology – requiring the driver to provide a breath sample each and every time before starting the vehicle. In the United States about 40 percent of the population indicate they do not drink and only about 3 percent of the population say they have driven after drinking during the last 12 months (Chou et al., 2006; Williams et al., 2000). Therefore, to be acceptable for use among all drivers, many of whom do not drink and drive, in-vehicle alcohol detection technologies must be seamless with the driving task; they must be non-intrusive, reliable, durable, and require little or no maintenance.

The technical challenges are substantial, however the possible benefits to society are compelling, with the potential to prevent almost 9,000 motor vehicle deaths every year if all drivers with BACs at or above the legal limit (0.08 g/dL) were unable to drive (Lund et al., 2007).

There has been growing interest among legislators to broaden the scope of in-vehicle technology to prevent alcohol-impaired driving, and several state governments in the United States have considered legislation to require it. In the 2004 legislative session three U.S. States (New Mexico, New York, and Oklahoma) considered legislation to mandate breath alcohol ignition interlocks on all new vehicles. In New Mexico a Governor's Task Force was established to study alcohol ignition interlock devices and provide recommendations concerning their broader use.

There also has been considerable international interest. In 2005, the provincial government of Ontario, Canada also explored a requirement to mandate alcohol ignition interlocks on all vehicles. In 2006, the Swedish government announced its intention to equip all commercial vehicles with alcohol ignition interlocks by 2010 and all passenger vehicles by 2012.

Since then, the focus in Sweden has shifted to the voluntary application of breath alcohol ignition interlocks as a primary prevention measure (i.e. in vehicles of drivers who have not been convicted of a DWI) among fleet vehicles, including local government vehicles. It has been decided that they will await the development of non-invasive technologies before pursuing universal deployment. The governments of Norway and Finland also have expressed support for this strategy. Because of concern about a number of deaths of innocent victims of alcohol-impaired drivers, the Japanese government also has expressed interest in developing a comprehensive technological solution to the alcohol-impaired driving problem.

A number of automobile manufacturers have indicated that they are developing driver alcohol detection systems for vehicles. Beginning in 2008, Volvo now offers the AlcoGuard™ as optional equipment on their vehicles sold in Sweden. This device is integrated into the vehicle's man/machine interface but still requires drivers to provide a breath sample each time before starting the vehicle. In August 2007, Nissan announced a concept car with multiple potential systems to measure drivers' BAC, including alcohol in drivers' breath and sweat. Saab also has indicated it is developing a breath-alcohol device for use in its vehicles.

As interest was growing in the United States and internationally for technological solutions to the alcohol-impaired driving problem, an International Technology Symposium was sponsored by MADD in June 2006. The potential of advanced technologies for preventing alcohol-impaired driving was considered and a timeline was developed for their development and deployment. Also discussed was the suitability of extant technologies that could be completely transparent to the driver, such as tissue spectroscopy and transdermal or ocular detection. Representatives of NHTSA, automobile manufacturers, researchers, and safety experts agreed that with collaborative research and development, in-vehicle devices meeting these needs might be developed and deployed within a 10-15 year time frame. There also was broad agreement that the time had come to pursue a technological approach to alcohol-impaired driving.

Cooperative Agreement

In February 2008, the Automotive Coalition for Traffic Safety (ACTS) and NHTSA entered into a Cooperative Agreement to explore the feasibility, potential benefits of, and the public policy challenges associated with a more widespread use of in-vehicle technology to prevent alcohol-impaired driving – known as the Driver Alcohol Detection System for Safety (DADSS) program. Funding for ACTS currently is provided by motor vehicle manufacturers (BMW, Chrysler, Ford, General Motors, Jaguar Land Rover, Mazda, Mercedes Benz, Mitsubishi, Nissan, Porsche, Toyota, Volkswagen).

The approach being taken is a non-regulatory approach that will encourage voluntary adoption. This 5-year, cost-sharing agreement requires that ACTS and NHTSA work together to engage in cooperative research that advances the state of alcohol detection technology. This effort seeks to develop technologies that are less-intrusive than the current in-vehicle breath alcohol measurement devices and that will quickly and accurately measure a driver's BAC in a non-invasive manner. These technologies will be a component of a system that can prevent the vehicle from being driven when the device registers that the driver's BAC exceeds the legal limit (0.08 g/dL in all U.S. states). Such devices ultimately must be compatible for mass-production at a moderate price, meet acceptable reliability levels, and be unobtrusive to the sober driver.

The agreement seeks to assess the current state of impairment detection devices, and to support the development and testing of prototypes and subsequent hardware that may be installed in vehicles. The goal, at the end of the 5-year program, is the practical demonstration of an alcohol detection subsystem, suitable for subsequent installation in a vehicle.

DADSS Project Team Organization

The overall DADSS Program Management is being carried out by ACTS with oversight by NHTSA. Technical research and development oversight is being undertaken under contract with QinetiQ NA/Foster-Miller, Inc.

Figure 1 shows the program team organization.

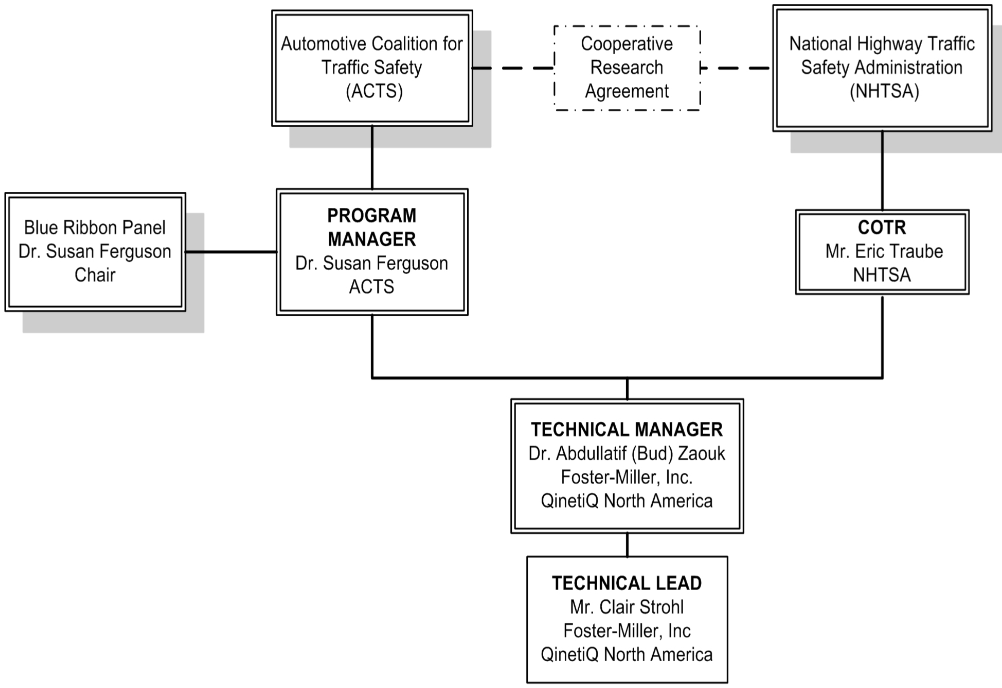

Figure 1. DADSS program team organization

ACTS has formed a Blue Ribbon Panel (BRP) of experts in order to consider the views of industry and other stakeholders. The BRP includes representatives from automotive manufacturers and suppliers, public interest organizations, government representatives both domestic and international, and experts in the science of alcohol toxicology, behavioral impairment, human factors, and research.

The BRP has assigned three working groups to assist in this effort. They are:

- The Research Plan Working Group, who have assisted in the development of the Program Management Plan and advised on the overall direction of the project.

- The Performance Specifications Working Group, who have assisted in the development of the Performance Specifications document. This document is the primary tool to direct the development of in-vehicle advanced alcohol detection technologies.

- The Public Policy Working Group, who will address the issues of public perceptions and attitudes towards in-vehicle alcohol detection systems for all drivers, to examine acceptability of alternative solutions and specifications, and to address relevant policy issues.

DADSS Program Details

The DADSS Program Management Plan, approved by NHTSA in May, 2008, laid out a timetable for development of the DADSS system, detailing the program's tasks, milestones and deliverables.

The current DADSS development and demonstration timeline is shown in Figure 2.

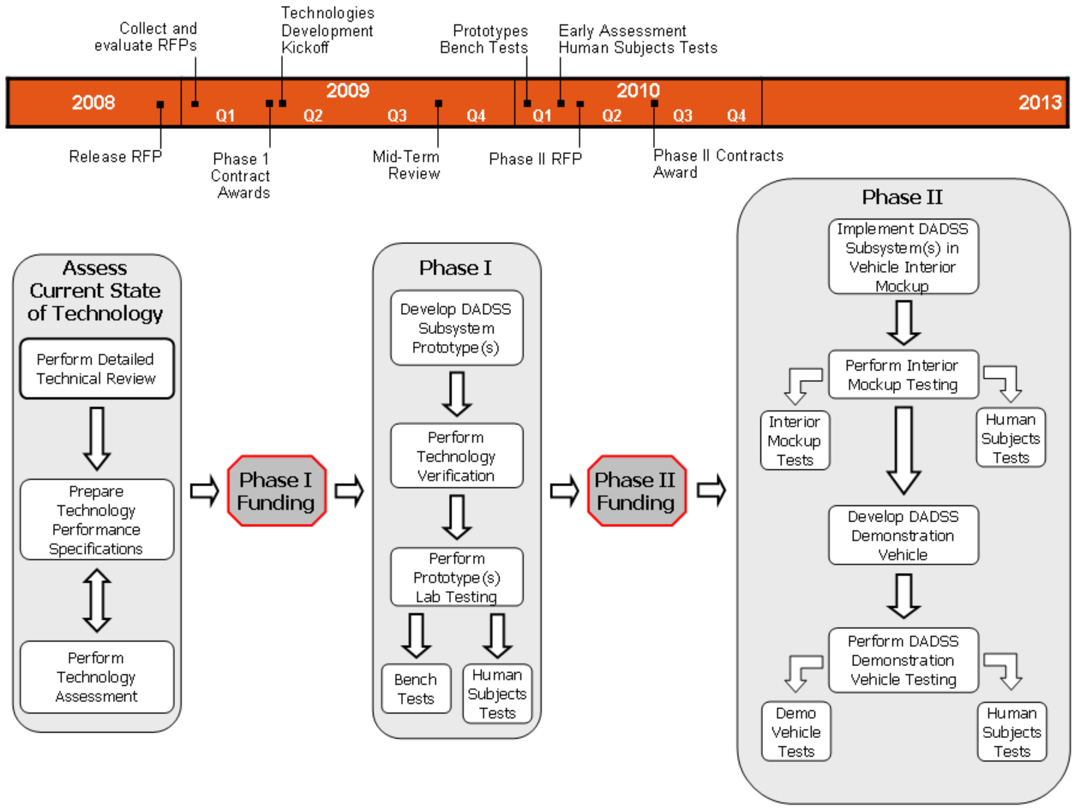

Figure 2. DADSS program development process

Detailed Technical Review

Once a Program Management Plan had been established, one of the first tasks of the project team was to perform a comprehensive review of emerging and existing state-of-the-art technologies for alcohol detection and to develop performance specifications. Prior to the commencement of the Cooperative Agreement, the Volpe National Transportation Systems Center of the U.S. Department of Transportation's Research and Innovative Technology Administration (Pollard et al., 2007) was tasked by NHTSA to identify current and emerging vehicle-based technologies and systems that can detect driver BAC and monitor driver impairment due to alcohol. The first undertaking of the literature review was to review the Volpe paper. The study included an assessment of the practicability and effectiveness of such systems and the capability of existing and anticipated technologies to detect and prevent alcohol-impaired driving. Additional technology scans were undertaken through patent and literature reviews, and these scans will be repeated periodically throughout the life of the program.

Technology Performance Specifications

Based on input from the BRP, ACTS developed performance specifications to assess the in-vehicle advanced alcohol detection technologies. The specifications are designed to address the current and future state of relevant emerging and existing advanced alcohol detection technologies. The influence of environment, issues related to user acceptance, long-term reliability and system maintenance are assessed, and the resulting list of specifications with definitions, measurement requirements, and acceptable performance levels are documented in the DADSS Subsystem Performance Criteria Document (http://dev.dadss.org/performance-specification/download). In the future, Vehicle Integration Specifications also will be developed.

Request For Information

A Request For Information (RFI) was published as a means by which the DADSS program was first communicated to potential vendors. The RFI was posted on the Federal Business Opportunities (FBO) web site, www.fedbizopps.gov on April 5, 2008. FBO is the single point-of-entry for Federal Government procurement opportunities with over 550,000 vendors and buyers registered. Additionally, direct notice went out to a list of vendors including all major alcohol detection technology developers, various medical technology associations, international contacts, and the BRP members.

The goal of the RFI was to establish the level of interest among technology developers in taking part in the research, the kinds of technologies available, and their states of development relevant to in-vehicle applications. The many responses received from industry provided a degree of confidence that there were numerous potential bidders. A 'first-order' assessment of what potential bidders were developing was completed by making visits to those companies that exhibited a strong grasp of the technologies necessary. A standardized visit report format allowed an initial cross-comparison of the companies visited.

Request For Proposals

Subsequent to the RFI process described above, a Request For Proposals (RFP) was issued by ACTS in November, 2008. Receipt of the RFP was restricted to a selected number of respondents to the RFI. The RFP solicited proposals from businesses with prior experience in alcohol detection or related technologies, for the development of in-vehicle devices meeting the ACTS requirements.

A two-phased R&D program

As shown in Figure 2 above, the DADSS R&D effort is following a two-stage process. Phase I will focus on developing a working prototype, and Phase II is the major R&D effort that will lead to a demonstration vehicle.

Phase I The specific objective for Phase I of this effort is to develop a Proof-of-Principle (POP) Prototype intended to represent a device capable of rapidly and accurately measuring the driver's BAC non-intrusively. The POP Prototype will be used to test several aspects of the intended in-vehicle alcohol detection technology design without attempting to simulate the visual appearance, choice of materials or intended manufacturing process. Its aim is to validate the potential design approach, as well as point to areas where further development and testing is necessary. The basis for awards will be the scientific and technical merit of the proposal and its relevance to ACTS requirements and priorities. Eligible institutions include for-profit, nonprofit, public, and private organizations, such as universities, colleges, hospitals, laboratories, and companies. Phase I is proceeding to plan, and awards are to be made to successful bidders before mid-2009, and will involve a 12-month period of performance.

Phase II is the principal R&D effort that will result in the practical demonstration of an alcohol detection subsystem, suitable for subsequent installation in a vehicle. The program is envisaged to span approximately two years. Phase II awards will be made only to those bidders that have achieved successful Phase I progress, with regard to the merits of their technological approach adopted, ACTS priorities, and the availability of appropriated funds to support the Phase II effort.

Potential technologies

Under the Phase I program, the successful contractors will commence the development of prototype devices based on various promising technological approaches. Such approaches may include, but not be limited to:

1. Tissue Spectrometry Systems that can measure alcohol concentration in tissue. A beam of light, at a wavelength that is sensitive to the presence and amount of alcohol in the tissue (within the near-infrared spectrum) is shone through the skin. The amount of light that is reflected and captured can be used to measure alcohol concentration.
2. Electrochemical Systems include transdermal systems that measure alcohol concentration present in a person's sweat, and advanced breath-based systems able to measure BAC through passive sampling of a driver's breath.

3. Distant Spectrometry Systems use an approach that is similar to tissue spectrometry, except that no skin contact is required. Infrared light is transmitted toward the subject from a source that receives and analyses the reflected and absorbed spectrum, to assess alcohol concentration in the subject's tissue or exhaled breath.

PUBLIC ACCEPTABILITY CHALLENGES

Although the current program is specifically focused on technology development it is recognized that there is a need to address public perceptions and attitudes towards such systems during the course of the program. Many of these issues are being addressed through the Blue Ribbon Panel and its subcommittees as these issues are intertwined with successful technology deployment. A non-regulatory, voluntary approach to in-vehicle driver alcohol detection systems will depend on public acceptance for its full implementation, and likely will be affected by a number of factors. It will depend on whether the public believes that alcohol-impaired driving is an important public health and safety issue that should be addressed by society collectively, or whether they think only those who drive impaired should shoulder the burden. It will likely depend on their own personal habits; whether they are teetotalers, social or heavy drinkers, and whether they drink and drive, how often, and how much. Public acceptance also may be influenced by personal experiences regarding alcohol-impaired drivers and whether they know anyone whose life has been impacted or cut short by an impaired driver. But most importantly, it will depend on how the technology is designed and introduced by vehicle manufacturers. It is paramount that it not impede the normal activities performed by the driver.

During the next few years research is planned to gauge drivers' perceptions of the alcohol-impaired driving problem, and their attitudes toward potential solutions. Research also will address what technology options will be publicly acceptable and how they might successfully be implemented. For example, how the general public views different measurement systems, the adoption of different operating thresholds, running retests, the need for an emergency override function and so on.

Communicating with the public

As the DADSS program develops there will be a need to educate the public about the DADSS program, the potential technologies that are being developed, and the way in which these might be implemented. A website, www.DADSS.org, has been launched to provide public access to the progress of the DADSS program. The web site provides key details of the DADSS development program progress, discusses issues associated with drinking and driving, and lists relevant research.

CONCLUSIONS

Government regulations are important in ensuring that vehicles meet a minimum standard of safety, but the process involved in producing new regulations necessarily takes time. There are many other ways in which vehicle safety can be advanced outside of the regulatory framework. Consumer crash-test assessment programs, now in place around the world, have been instrumental in advancing vehicle safety on a faster schedule than would have been possible through regulation. Increasingly, voluntary approaches to the design and implementation of vehicle safety systems play an important role as vehicle manufacturers deploy safety systems well in advance of, and even in the absence of, government regulations requiring them.

Public/private partnerships also have a crucial role to play. They can accelerate efforts to implement new safety technologies and they can provide an important mechanism for developing workable approaches that are acceptable both to government and industry. For example, the Side Airbag Technical Working Group developed voluntary test procedures to assess the potential of side airbags to injure out-of-position occupants within 15 months of being asked to do so by the government. Side airbags, though not required by regulation, now are in more than two-thirds of 2008 model vehicles http://www.iihs.org/ratings/side_airbags/side_airbags.aspx) .

The DADSS program represents the latest and most innovative public/private partnership that aims to develop and demonstrate a critically important advance in highway safety – that of keeping alcohol-impaired drivers from driving. Starting with a requirement to develop a non-invasive technology that will quickly and accurately measure a driver's BAC, the project team has established a Program Plan, developed Performance Specifications, solicited industry interest, and begun the process of identifying technological approaches that show promise. The goal at the end of the 5-year program is the practical demonstration of an alcohol detection subsystem which is suitable for subsequent installation in a vehicle.

The adoption of non-regulatory, voluntary approaches to the implementation of advanced vehicle technology makes it critical that policy and public acceptance issues be addressed concurrent with the technology development. This is particularly important when it comes to the widespread implementation of technologies to prevent alcohol-impaired drivers from getting behind the wheel. The majority of the driving public in the United States either does not drink, or does not drink and drive. It is therefore necessary that advanced technologies to assess BACs must be seamless with the operation of the vehicle and not impede the sober driver.

The general public fully understands the dangers of drinking and driving. In a survey on drinking and driving attitudes and behavior (NHTSA, 2003), ninety-seven percent of respondents indicated that drinking and driving is a threat to their personal safety. With the growing public perception that vehicle safety is an important factor in the vehicle purchase decision, advances in safety technology are gaining public acceptance more readily than in the past. Communicating with the public regarding the DADSS program, the potential technologies that are being developed, and the way in which these might be implemented will be an important component of this effort.

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A PROPOSED ROLLOVER AND COMPREHENSIVE RATING SYSTEM

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ABSTRACT

The US, European and Australian New Car Assessment Program (NCAP) [1] and the Insurance Institute for Highway Safety (IIHS) produce ratings of new vehicle performance based on dynamic crash tests in frontal, side and rear crashes; and vehicle handling tests. No dynamic based crashworthiness ratings exist to date in relation to rollover crashes [2]. This study fills that gap and proposes a rating system for new vehicle performance in rollover crashes. Combined with existing rating systems, consumers will then have a complete and balanced picture of occupant protection performance.

A database of more than 40 Jordan Rollover System (JRS) dynamic rollover tests [3], [4], [5] assessing injury potential by roof crush and crush speed has generically validated NHTSA and IIHS statistical data as a function of FMVSS 216 quasi-static, strength to weight ratio (SWR) [6].

There is however a wide disparity between the performance of individual vehicles at the same or similar SWR between the IIHS statistical and JRS dynamic test data. That disparity has been partially investigated in a companion paper in this conference (Vehicle Roof Geometry and its Effect on Rollover Roof Performance [7]).

IIHS data indicated [8], [9] a 50% reduction in incapacitating and fatal injury risk with a fleet average SWR = 4. However, the use of a SWR-based rollover criterion does not provide sufficient crashworthiness fidelity essential for consumers, nor does such a criterion provide industry the opportunity to design cost-efficient rollover crashworthy vehicles based on occupant injury performance. Only a dynamic rollover testing protocol based on injury criteria would provide this information.

INTRODUCTION

NHTSA, in 1973, established a 13 cm (5") occupant head and neck survival space criterion [10]. In 1995 [11], NHTSA proposed a post-crash negative headroom injury criterion and, in its 2005 [12] and 2007 [13] statistical studies, authenticated [14] that criterion to be five times more likely to result in injury. In 1979, the onset of head and neck injury was determined to be a head impact at 11 km/h (7 mph) as a consensus injury measure [15]. Recently, IIHS, based on its SUV and passenger car rollover crash statistical studies and quasi-static tests, announced that it will provide rollover roof crush crashworthiness ratings for 2010 model year vehicles. Their "good" rating criteria requires a SWR of 4.

This paper evaluates the generic dynamic JRS injury potential rating for far side occupants by the roof intrusion and intrusion speed criteria and compares it to the FMVSS 216 SWR ratings.

Under the auspices of the Center for Auto Safety and funding by the Santos Family Foundation and State Farm Insurance Company, the Center for Injury Research has completed JRS tests on 5 current model passenger cars and 5 current model light truck vehicles (LTV's). Our analysis of the 10 JRS tests is the basis for our proposed rollover and comprehensive rating system.

This paper assembles these results and discusses the disparities, which exist as a result of geometry and design techniques that cannot be evaluated in the FMVSS 216 static tests. Details of the geometry and design technique disparities are discussed in a companion paper submitted in this conference entitled "Vehicle Roof Geometry and its Effect on Rollover Roof Performance" [7].

METHODS

Developing a predictive rollover injury potential rating system requires generic correlations with real-world crash injury data, a repeatable dynamic test machine, a representative rollover impact protocol, reasonably validated experimental injury criteria and appropriate measuring devices. Although the scientific reliability and repeatability of the JRS has been affirmed [16], comparative dynamic results will not be available from a multiplicity of facilities until early next year.

The proposed IIHS rating effort is to quasi-statically test 2010 vehicles and to rate them according to SWR. The JRS test results are compared here to the SWR rating to assess whether this strategy would provide sufficient information to ascertain occupant protection performance.
The preliminary data indicates that strategy may not work as well as expected by consumer rating groups, such as IIHS and NCAP. Instead, we propose to supplement JRS results with both geometric data and quasi-static two-sided roof strength tests, with one side conducted at a 10º pitch angle.

Biomechanics Data

Separate papers regarding the biomechanical equivalent measurements and criteria using the Hybrid III dummy data, interpreted to represent real-world injuries, have been published [17], [18]. Work is continuing. NHTSA post-crash headroom is based on cumulative crush data and is not an accurate representation of injury. Head and neck injuries are a function of the impact crush and crush speed in any individual roll. Head injuries are not accumulated; they occur during one roll or another when struck at more than 16 to 19 km/h (10 to 12 mph). Neck bending injuries predominate and are not accumulated; they occur during one roll or another when the head is struck at more than 11 km/h (7 mph) with a maximum dynamic crush of more than 15 cm (6") and residual crush of more than 10 cm (4").

JRS Test Device

Figure 1 shows the JRS test device. Descriptions of how the test rig functions are described elsewhere [3], [4], [5]. The ends of the vehicle are mounted on towers on an axis of rotation through its Center-of-Gravity (CG). The vehicle is simultaneously rotated and released as a roadbed moves under it. The test is commenced from an almost vertically-oriented to the road bed position similar to that shown in Figure 1.

Figure 1. JRS Dynamic Rollover Test Device

During the simultaneous rotation and fall, the vehicle strikes the moving roadbed below on the leading side of roll (near side) at the side roof rail at the prescribed roadbed speed, vehicle angular rate, drop height and impact pitch angle. After striking the near side the vehicle continues to roll and strikes the side opposite to the leading side (far side). The vehicle is then captured. The motions of the vehicle and roadway are coordinated so that the touchdown conditions can be controlled and thus repeated within a narrow range that was considered acceptable in other crash test protocols used by IIHS and NCAP.

A 50th percentile Hybrid III Anthropomorphic Test Dummy (ATD) is used to monitor head and neck loads in the driver seat position. String potentiometers are used to measure roof intrusion and intrusion rates, as well as the ATD's motion. High-speed cameras also record vehicle and ATD motions. The ATD is setup according to the FMVSS 208 protocol.

In the first roll, the vehicle is set at 5º pitch angle whereas in the second roll the vehicle is set at 10º pitch angle. Roll rate at 190º per second, yaw at 10º and roadway speed at 24 km/h (15 mph or 6.7 m/s) are the same for each of the two rolls. Typical charts of far side roof crush, crush speed, and road load are shown in Figures 2 and 3. The results from a JRS study involving ten newer vehicles tested are shown in Figure 4 and 5.

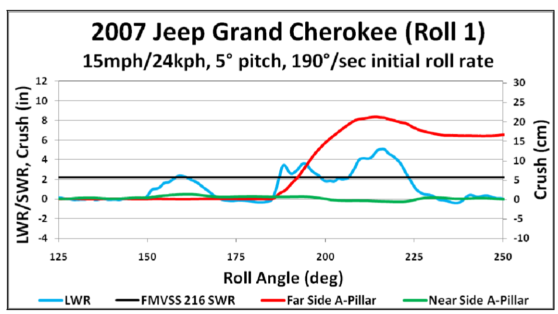

Figure 2. Far Side Crush Graph by Roll Angle.

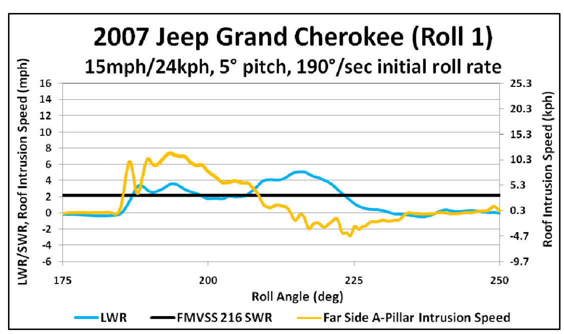

Figure 3. Far Side Intrusion Speed by Roll Angle.

	2007 VW Jetta		2007 Toyota Camry		2006 Hyundai Sonata		2006 Chrysler 300		2006 Pontiac G6	
	Roll 1	Roll 2	Roll 1	Roll 2	Roll 1	Roll 2	Roll 1	Roll 2	Roll 1	Roll 2
Roof FMVSS 216 SWR	5.1	5.1	4.3	4.3	3.2	3.2	2.5	2.5	2.3	2.3
Road Speed (kph)	24	24	24	24	24	24	24	24	24	24
Pitch Angle at Impact (deg)	5	10	5	10	5	10	5	10	5	10
A-Pillar										
Peak Dynamic Crush (cm)	6.9	16.0	8.6	18.3	11.9	17.5	21.3	26.4	18.0	25.4
Cumulative Residual Crush (cm)	2.5	8.6	4.1	10.9	6.6		14.2	18.8	12.4	17.8
Maximum Crush Speed (kph)	9.2	11.4	8.0	13.2	8.0	--	12.07	17.06	12.07	21.08
B-Pillar										
Peak Dynamic Crush (cm)	3.8	6.1	4.6	10.7	--	6.6	11.2	13.5	9.1	15.0
Cumulative Residual Crush (cm)	1.5	3.3	1.8	5.3	--	2.0	6.9	8.6	6.4	8.6
Maximum Crush Speed (kph)	6.1	5.6	5.1	8.0	--	6.6	8.7	12.23	10.14	14.32
Compressive Neck Load, Fz	5158	5394	4211	2669	4835	3457	5598	1979	2399	1916
Peak Upper, Flexion Moment (N m)	279	318	--	--	--	--	414	155	198	155
Upper Neck, Nij*	0.96	1.08	0.78	0.76	1.63	1.15	1.80	0.40	0.66	0.54
Lower Neck, Nij**	1.17	1.28	--	--	--	--	1.44	0.57	0.68	0.54

*Based on by NHTSA: Compression 6160 N, Flexion 310 Nm, Extension 135 Nm

**Based on values presented in Mertz, et. al, 2003: Compression 6200 N, Flexion 610 Nm, Extension 266 Nm

	2005 Volvo XC90		2007 Honda CRV		2006 Honda Ridgeline		2007 Jeep Grand Cherokee		2007 Chevrolet Tahoe	
	Roll 1	Roll 2	Roll 1	Roll 2	Roll 1	Roll 2	Roll 1	Roll 2	Roll 1	Roll 2
Roof FMVSS 216 SWR	4.6	4.6	2.6	2.6	2.4	2.4	2.2	2.2	2.1	2.1
Road Speed (kph)	24	24	24	24	24	24	24	24	24	24
Pitch Angle at Impact (deg)	5	10	5	10	5	10	5	10	5	10
A-Pillar		***								
Peak Dynamic Crush (cm)	4.3	8.1	8.6	16.5	19.8	36.6	21.3	30.0	20.1	35.6
Cumulative Residual Crush (cm)	1.3	2.5	4.6	9.1	12.7	27.7	16.5	23.1	14.7	27.7
Maximum Crush Speed (kph)	3.1	5.1	6.4	8.5	13.2	24.1	11.75	13.84	9.8	18.67
B-Pillar										
Peak Dynamic Crush (cm)	3.0	5.3	5.1	8.6	15.2	28.2	18.5	25.7	13.2	24.9
Cumulative Residual Crush (cm)	0.5	1.8	2.0	3.6	8.6	18.8	14.2	19.8	8.9	17.5
Maximum Crush Speed (kph)	2.7	3.5	4.2	5.5	9.0	11.1	12.71	10.46	6.8	11.27
Compressive Neck Load, Fz	2889	3628	5583	3687	10006	4685	9757	6781	6101	3318
Peak Upper, Flexion Moment (N m)	128	259	255	328	492	324	470	396	304	247
Upper Neck, Nij*	0.52	1.05	1.02	1.30	1.64	1.19	1.75	2.07	1.09	0.81
Lower Neck, Nij**	0.62	0.87	1.20	1.10	2.10	1.06	2.00	1.59	1.02	0.87

*Based on by NHTSA: Compression 6160 N, Flexion 310 Nm, Extension 135 Nm

**Based on values presented in Mertz, et. al, 2003: Compression 6200 N, Flexion 610 Nm, Extension 266 Nm

*** Determined through photoanalysis of High Speed Video

Figure 4 and 5. List of 10 current production vehicles subjected to two JRS tests.

The main reason that the vehicle is subjected to two rollover events in the JRS is based on observations published by Digges and Eigen [19]. They showed that rollover crashes lasting 8 quarter turns or less (i.e. two full rolls) accounted for more than 90% of all rollover crashes, where a fatal or serious injury experienced by occupants was recorded.
The generic slope composite chart shown in Figure 6 presented by Paver et al [20] and by Friedman [21] that compares injury criteria and injury rates versus SWR from previous papers correlates well with NHTSA and IIHS data versus FMVSS 216. It indicates that an SWR of about 4 would be "good".

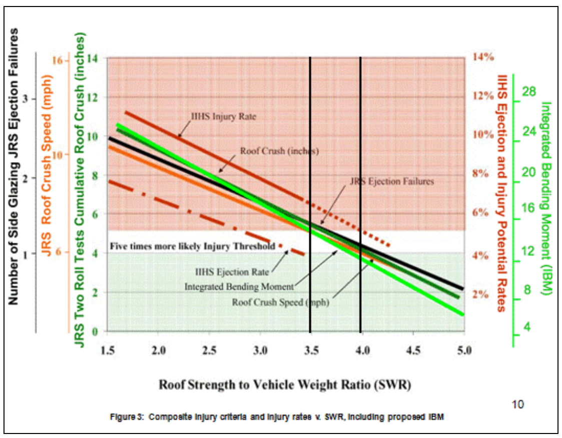

Figure 6. Composite NHTSA, IIHS, and JRS Injury Criteria.

M216 10° of Pitch Quasi-Static Tests

The M216 test machine is shown in Figure 7. It is a fixture with two platens, both oriented with 10° of pitch and one side at 25° of roll and the other at 40° of roll.

Figure 7. Modified FMVSS 216 Fixture (M216).

Figure 8 indicates the second side SWR performance of some of the 40 vehicles which have been tested.

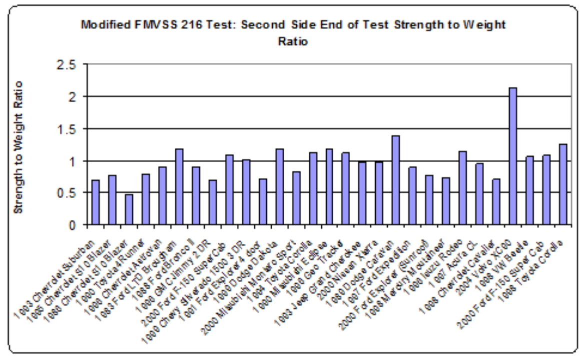

Figure 8. Second Side M216 versus 216 SWR.

Figure 9 describes the relationship between M216 results and FMVSS 216 with confidence limits.

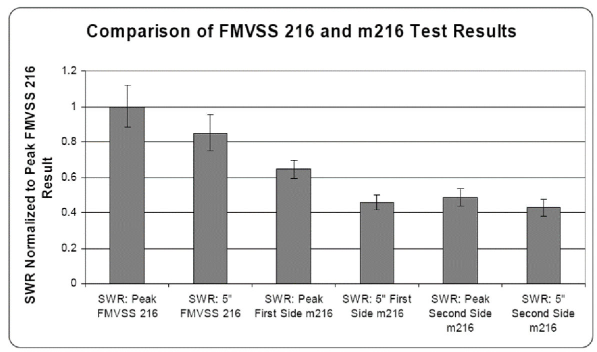

Figure 9. M216 and 216 Relationship with Confidence Limits.

Figure 10 is a scatter plot of the relationship between M216 tests of production vehicles and their SWR. Because serious injuries are strongly related to 10° of pitch crashes in the National Accident Sampling System (NASS) [22], [23] it would seem appropriate to factor a second side quasi-static test performance into a predictive rating. Such a test could also provide an indication of the vehicles structural elasticity, another factor important to its injury potential performance.

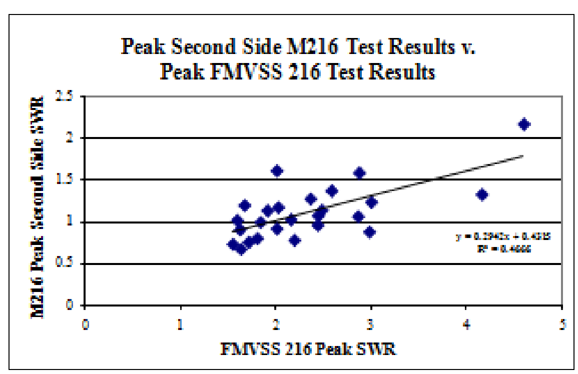

Figure 10. Scatter Plot of Production M216 and SWR.

Geometric Considerations

Experimental [7] and empirical (NASS) [22] data suggest that geometrical and dimensional vehicle configurations influence how vehicles roll. Front-wheel drive vehicles tend to roll with substantial forward pitch stressing windshield pillars, which are generally weak and undetected by FMVSS 216.

It is estimated that a difference between the major and minor radius of a vehicle (its rollover "roundness") of only a few centimeters (inches) can play an important role in the ability of the roof structure to remain intact. The Honda CRV is the roundest of the 10 JRS-tested vehicles both in transverse section and the longitudinal rake of the windshield and roof as shown in Figure 11.

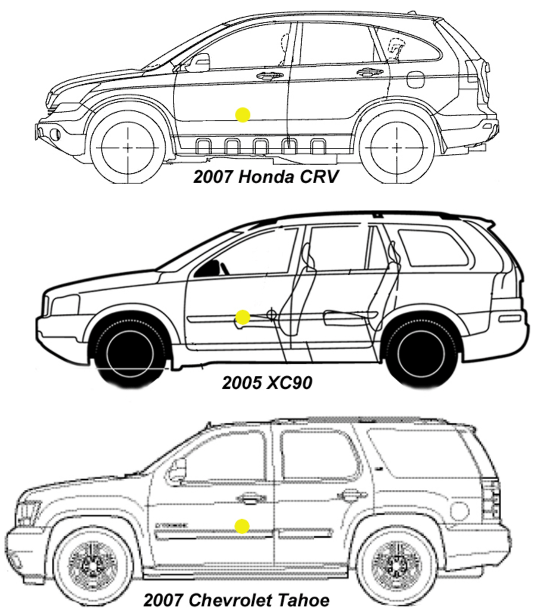

Figure 11. Geometric differences with CG.

Other geometric factors not discernable in static tests, nor yet explored are: the CG position relative to the windshield header, the weight distribution (shifting of the CG), the pitch moment of inertia and the vehicle height-to-width ratio.

RESULTS

Generic Ratings

A rating system requires criteria. For the quasi-static performance, we assumed:

- an SWR of 4 or more would be "good,"
- more than 3 would be "acceptable,"
- more than 2 would be "marginal," and
- less than 2 would be "poor."

We compared the FMVSS SWR to the maximum residual and dynamic intrusion of some 40 vehicles (including the 10 current production vehicles shown in Figure 4 and 5). For the JRS generic data, we used the NHTSA residual crush and the cumulative residual crush criteria. Since 65% of serious injury rollovers are completed in four quarter turns, for residual crush after one roll, we used:

- less than 5 cm (2") per roll to represent "good" performance,
- less than 10 cm (4") to represent "acceptable" performance,
- less than 15 cm (6") to represents "marginal" performance, and
- more than 15 cm (6") to represent "poor" performance.

For cumulative residual crush after two rolls which covers 95% of all serious injury rollover crashes[19], we used:

- less than 10 cm (4") to represent "good" performance,
- less than 15 cm (6") to represent "acceptable,"
- less than 20 cm (8") to represent "marginal," and
- more than 20 cm (8") to represent "poor" performance.

For maximum dynamic crush, we used:

- less than 10 cm (4") to represent "good" performance,
- less than 15 cm (6") to represent "acceptable,"
- less than 20 cm (8") to represent "marginal," and
- more than 20 cm (8") to represent "poor" performance.

Similarly, with respect to intrusion speed, in any roll:

- "good" is represented at less than 10 km/h (6 mph),
- "acceptable" is 10 to 13 km/h (6 to 8 mph),
- "marginal" is 13 to 16 km/h (8 to 10 mph), and
- "poor" is more than 16 km/h (10 mph).

Specifically, each of the scatter charts are ordered by SWR versus JRS dynamic data. The ratings "good", "acceptable" ,"marginal"and "poor" were chosen based on consensus injury measures for crush and intrusion velocity [8-15]

Figure 12 represents a scatter plot of the composite of all JRS tests for the first roll by residual crush. All plots are segmented by the criteria for SWR and JRS dynamic tests.

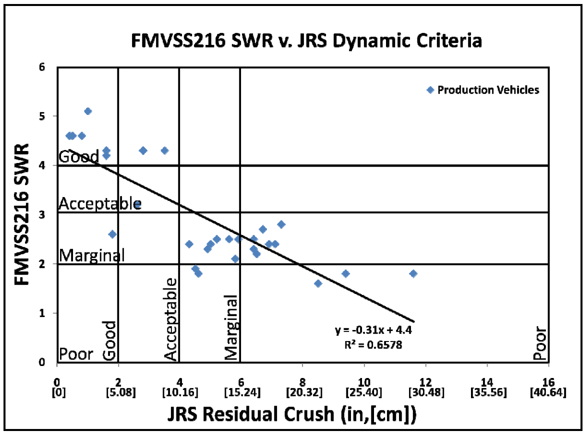

Figure 12. JRS Testing Results for Residual Crush After One Roll.

Figure 13 is the cumulative residual crush from two JRS roll tests.

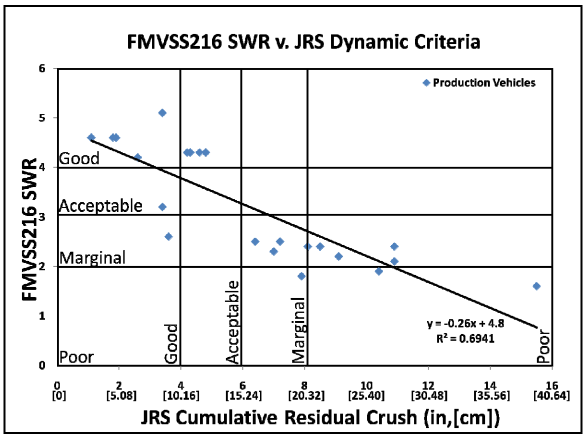

Figure 13. JRS Testing Results for Cumulative Residual Crush After Two Rolls.

Figure 14 is the same scatter plot by maximum intrusion speed.

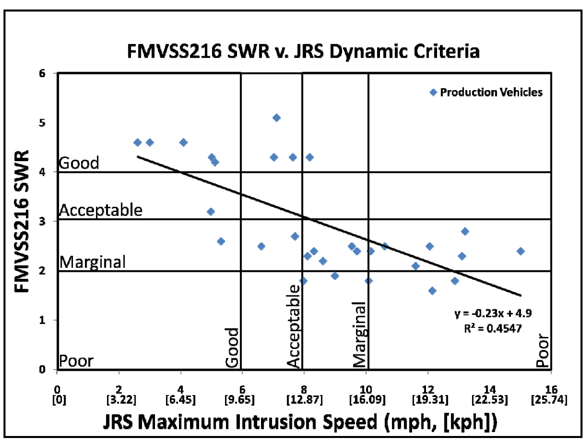

Figure 14. JRS Testing Results for Maximum Intrusion Speed.

Figure 15 is the same scatter plot by maximum dynamic crush.

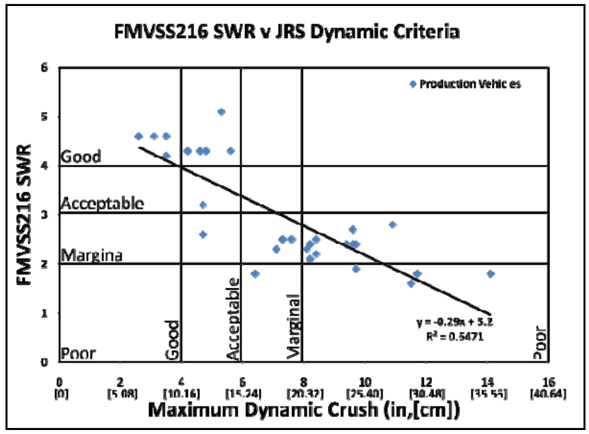

Figure 15. JRS Testing Results Maximum Dynamic Crush.

Current Production Vehicle Testing by SWR versus JRS Ratings

Scatter plots for the 10 vehicle set all with the same protocol will now be looked at. Figure 16 and 17 show the disparity between LTV's and passenger cars. This is more specifically identified by residual crush after roll 1 and then cumulative crush after roll 2.

Figure 16 shows the residual crush results after roll 1, where 3 passenger cars and 2 LTV's fall in "acceptable" or "good" in JRS testing and 6 fall below the "acceptable" level. 3 passenger cars and only 1 LTV are better than "acceptable" for SWR.

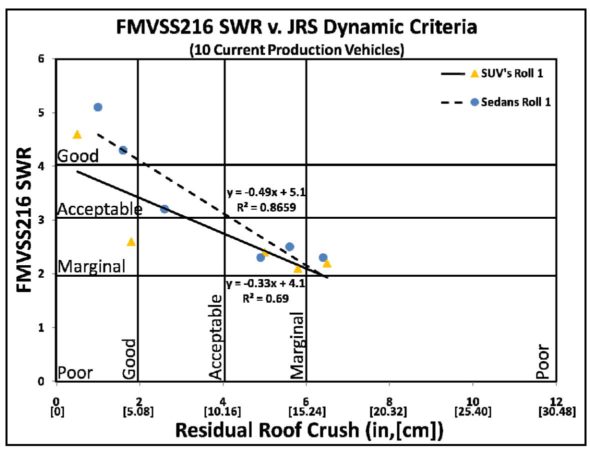

Figure 16. JRS Test Results, Current 10 Vehicles by Residual Crush, by LTV's and Sedans.

Figure 17 is by cumulative residual crush and shows that the disparities are larger when you factor in the second roll at 10º of pitch. The sedans held their relative positions, while three of the LTV's fall to a "poor" in JRS testing. Those anomalies are thought to be associated with vehicle parameters discussed in Figure 11 and in the companion geometry paper. [7]

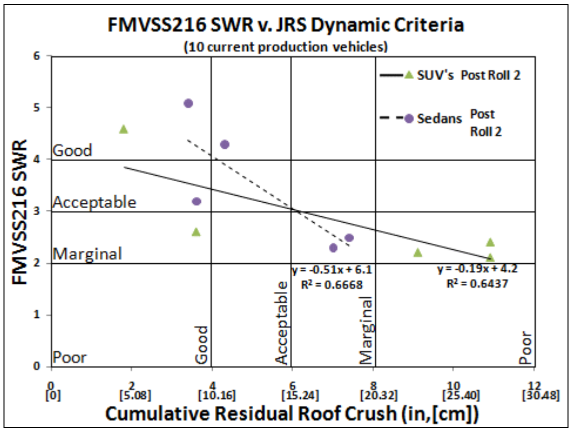

Figure 17. JRS Test Results, Current 10 Vehicles by Cumulative Residual Crush, Post Roll 2.

Figure 18 shows the relationship between maximum intrusion speed in JRS tests and FMVSS 216 SWR. The disparities between the JRS and FMVSS 216 measurements again are significant in the second roll at 10º of pitch. Note how the squares (roll 2) are shifted toward "poor" ratings versus their diamond equivalents for roll 1. Those anomalies demonstrate the shortcomings of FMVSS 216 as a measure of a vehicle's actual dynamic performance in a rollover.

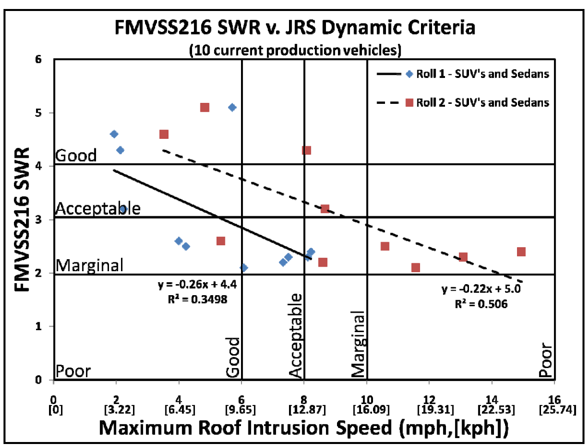

Figure 18. JRS Test Results, Current 10 Vehicles by Maximum Intrusion Speed, Rolls 1 and 2.

Figure 19 shows the amount of maximum dynamic crush in each roll of each vehicle. Note that three of the vehicles move to the left, meaning they had less dynamic crush in the second roll. Vehicles like the Pontiac G6, that crush significantly in roll 1, like 20 cm (8"), cannot crush as much in roll 2. The vehicles that have more than 15 cm (6") of crush in any roll are likely to be seriously injurious. Of the twenty rolls shown, three are likely to be serious injuries and five to be severe injuries.

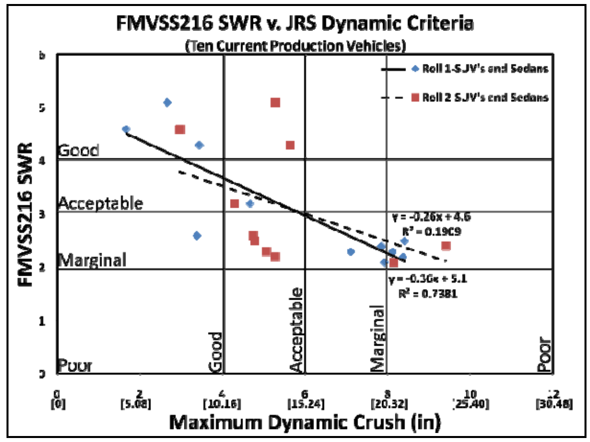

Figure 19. JRS Test Results, Current 10 Vehicles by Maximum Dynamic Crush.

Rating individual vehicles to correspond to real world injuries as a predictive rating function requires multi-dimensional correlation.

The dynamic characteristics of a vehicle are related to injury potential. The nonlinearity of roof deformation and the ability to predict the occupants' head position with the current restraint systems and the non-biofidelic Hybrid III dummy can be misleading. In all recent tests we have measured near and far side roof deformation in front of and behind the dummy which is located at about the mid roof rail position as well as lower neck load, moment, and duration. While this paper will not discuss the biomechanics of dummy injury measures it should be noted that the bending of the neck was related to human injury and an integrated bending moment (IBM) was closely related to vehicle intrusion.

Head and neck injuries are not accumulated, they occur during one roll or another when struck at more than 11 km/h (7 mph) with crush of more than 10 cm (4"). Figures 20 to 23 highlight and identify the outliers of the 10 production vehicle where the SWR and JRS dynamic ratings do not match by two criteria levels. We are currently investigating the factors which make those vehicles unique within the broad range of each rating. When using SWR as the rating basis the Honda CRV with a SWR of 2.6 is "marginal" but by JRS dynamic rating is "good" in residual crush and cumulative crush as shown in Figures 20 and 21. The dynamic rating is two rating levels better than the SWR rating. It would not be fair to penalize a manufacturer who has created a structure which is better from an occupant's protection point of view.

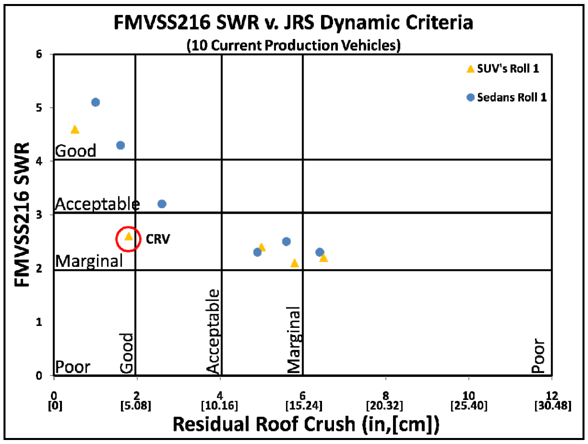

Figure 20. Highlighted Anomaly – CRV.

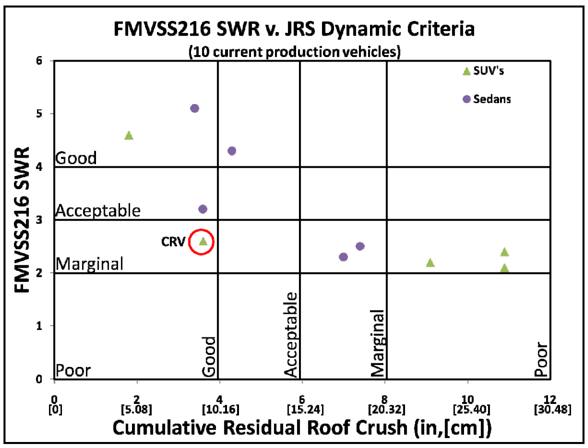

Figure 21. Highlighted Anomaly – CRV.

Maximum Intrusion Speed in roll 1 and 2 for the 10 vehicles tested is shown in Figures 22 and 23, with the vehicles that did significantly worse on the second roll of the dynamic testing highlighted. In Figure 22, the Camry and Sonata fell two levels to a "marginal" rating and the Chrysler fell two levels to a "poor" rating, after having "good" dynamic ratings for roll 1.

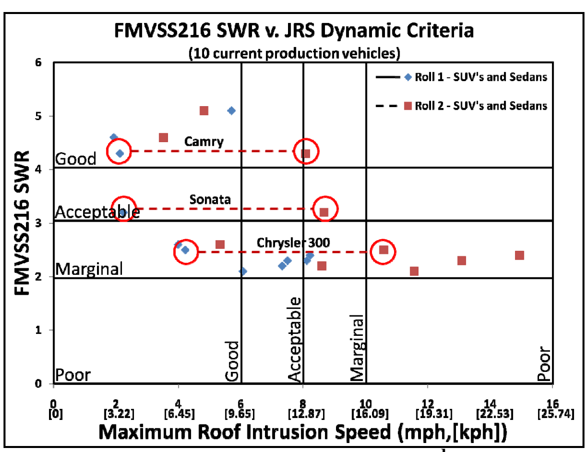

Figure 22. Highlighted Anomalies – 2nd roll rating.

Figure 23 highlights the CRV against the XC90 and Jetta, showing that the SWR rating of "marginal" is given, yet both rolls in the dynamic test remain at "good".

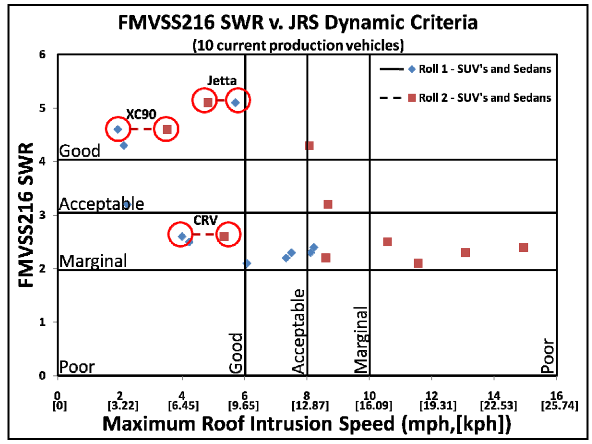

Figure 23. Highlighted Anomalies for Maximum Intrusion Speed – CRV.

The conclusion has to be that the disparity between FMVSS 216 SWR and JRS dynamic test results show that FMVSS 216 data alone is unacceptable for real world rollover ratings.

Considerations for the Proposed Rating System

Most vehicles when tested at 10º of pitch in the M216 test have half the strength of the FMVSS 216 test. This makes them vulnerable to excessive intrusion on a 10º of pitch roll. The XC-90 was subjected to an M216 test and resisted to a SWR of 2.2 about half its 216 SWR (two times most others, and apparently adequate).

Nash initially studied 273 cases and then expanded his study to 500 serious injury rollovers in NASS and found that roughly 60% of the vehicles had some top of fender and hood damage, consistent with more than 10º of pitch. [23]

This suggests that, at a minimum, any rollover rating system based on a FMVSS 216 one sided test be modified to also measure the second side at 10º of pitch and adjust the ratings on the basis of the results. JRS tests with anthropomorphic dummies and various types of padding and seatbelt systems have thus far been clouded by excessive roof crush and debate concerning the biofidelity of the ATD in measuring rollover related injury potential. Looking at the interior videos makes it clear that roof crush is a primary cause of injury to belted, unbelted, and ejected occupants. If roof strength can be increased to a 5º of pitch SWR of 4 or more and, a second side at 10º of pitch to more than an SWR of 2, then other safety systems will come into play and can be evaluated and factored into the ratings.

The Proposed Rollover Rating System

Figures 24 and 25 illustrate the way the proposed dynamic rollover rating system would be constructed. Figure 24 shows the relationship between two criteria; crush and crush speed for both rolls of the five LTVs (4 LTVs and one four door pick-up). Their performance is plotted on a formatted chart with the assigned rating categories of good, acceptable, marginal and poor. The two roll results are connected and identified for each vehicle. It is easy to see that the XC-90 (denoted 1) performed entirely in the "good" category and the CRV (denoted 2) was also "good" with slightly higher crush and speed. The other three vehicles are problematic because they performed so poorly in the second roll at 10º of pitch. We would weigh the rating assignment on the basis of the probability of these vehicles rolling with 10º of pitch as determined from geometric considerations. The performance of any vehicle in 10º of pitch circumstances may be assessed by the M216 second side test. Figure 25 is the same format plot for the 5 passenger cars.

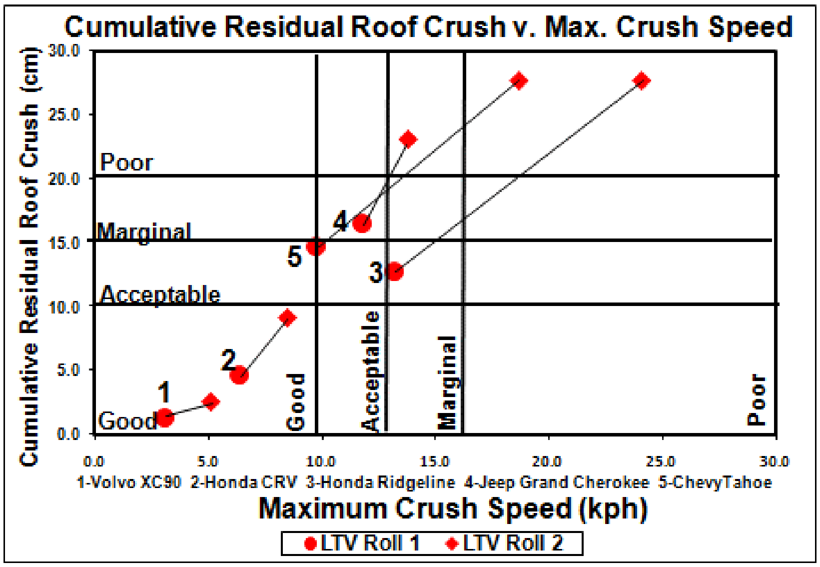

Figure 24. JRS Test Results, Current 5 LTV Vehicle Ratings for Two Rolls.

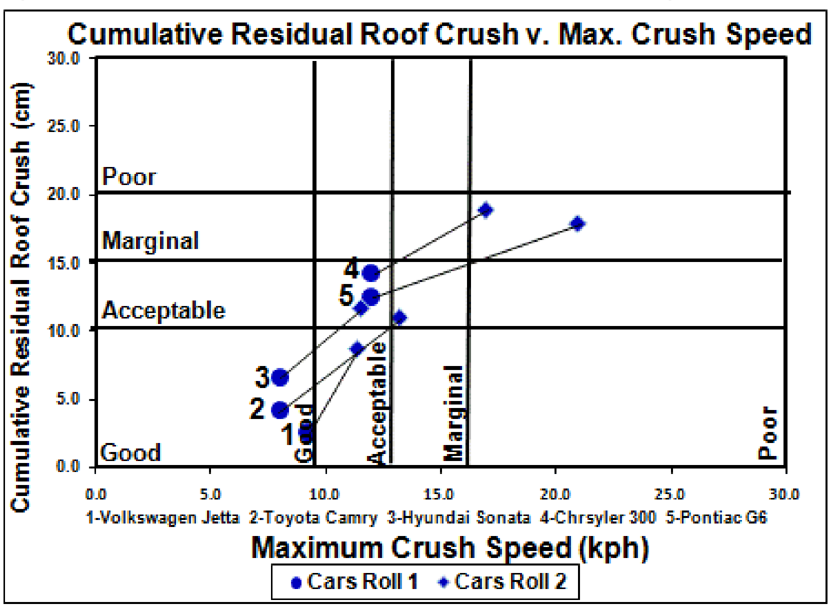

Figure 25. JRS Test Results, Current 5 Passenger Car Vehicle Ratings for Two Rolls.

The decision as to which rating to choose would be based first, on the amount of crush, and second, on the impact speed. This is because if there were no more than 10 cm (4") of dynamic crush, the speed would be irrelevant for neck injury, although if the speed were high enough, you could get a head injury. If the dynamic crush were 15 cm (6") then a speed of 11 km/h (7 mph) would onset of serious neck injury.

Based on those criteria the XC-90, CRV, and Jetta would be rated "good". Considering the probability of 10 º of pitch, the Camry and Sonata would be rated "acceptable". The Chrysler 300 and Cherokee would be rated "marginal". The G6, Tahoe, and Ridgeline would be rated "poor".

The purpose of this paper is to illustrate a dynamic rollover rating system, not to argue the biomechanical criteria. It is for that reason a speed consensus criterion and NHTSA derived (post crash negative headroom) cumulative crush data was used. It would be more appropriate but more controversial to use dynamic crush. In that regard the procedure is flexible and the ratings would perhaps only be more accurate but likely not shifted to a new level. It would also provide vehicle manufacturers the opportunity to design lighter, fuel efficient vehicles that are rollover crashworthy.

Based on the overall analysis of these ten vehicles for the JRS dynamic two roll testing, our proposed dynamic rollover ratings are shown in Table 1.The vehicles in bold type denote the disparity in rating using the dynamic versus SWR ratings base.

Year/Make/Model	JRS Dynamic Rating	SWR Rating
2007 VW Jetta	Good	Good
2007 Toyota Camry	**Acceptable**	**Good**
2006 Hyundai Sonata	Acceptable	Acceptable
2006 Chrysler 300	Marginal	Marginal
2006 Pontiac G6	**Poor**	**Marginal**
2005 Volvo XC90	Good	Good
2007 Honda CRV	**Good**	**Marginal**
2006 Honda Ridgeline	**Poor**	**Marginal**
2007 Jeep Grand Cherokee	Marginal	Marginal
2007 Chevy Tahoe	**Poor**	**Marginal**

Table 1.
Dynamic Rollover Ratings for JRS Tested Current Production Vehicles

Table 1 shows that the difference between JRS Dynamic and SWR ratings for the ten vehicles includes five matches. The CRV is two rating levels better dynamically, where as the Camry, G6, Ridgeline and Tahoe are one level lower rated dynamically.

COMPREHENSIVE RATING SYSTEM

The comprehensive rating system would provide consumers with an idea of the overall safety of a particular vehicle. The proposed rating system would incorporate a rating for 4 different crash modes; front, side, rear, and rollover. Three of the four types of crash modes are currently being rated by the IIHS, Euro NCAP, ANCAP and other consumer rating groups, on a "good," "acceptable," "marginal," "poor" scale. The 4th rollover rating would be provided by the proposed JRS dynamic rollover rating system on the same scale. By combining the ratings for all 4 crash modes a composite rating can be established.

This would be done by computing a weighted average of these 4 ratings based on the frequency and fatality rate that occurs annually per crash mode. Calculating the average rating in this way gives more weight to the rollover crash mode that results in the highest fatality rate. Therefore a vehicle that performed very well in front, side and rear impact tests but not very well in rollover tests would be rated significantly less safe than a vehicle that performed very well in front, side and acceptably in rollovers.
The individual mode ratings for the ten vehicles of this paper are shown in Table 2.

Year/Make/Model	Offset-Frontal *	Side *	Rear *	Dynamic Rollover
2007 VW Jetta	4	4	2	4
2007 Toyota Camry	4	4	2	3
2006 Hyundai Sonata	4	3	4	3
2006 Chrysler 300	4	1	2	2
2006 Pontiac G6	4	1	2	1
2005 Volvo XC90	4	4	4	4
2007 Honda CRV	4	4	4	4
2006 Honda Ridgeline	4	4	2	1
2007 Jeep Grand Cherokee	4	2	4	2
2007 Chevy Tahoe	N/A	N/A	N/A	1

4 - Good 3 - Acceptable 2 - Marginal 1 - Poor
* Ratings from NHTSA Vehicle Ratings website (N/A - Not Available)

Table 2.
Individual Crash Mode Ratings for 10 Vehicles.

CONCLUSIONS

- A consumer rollover rating system is long overdue. The best way to rate the crashworthiness injury potential of vehicles in rollovers is by utilizing a JRS dynamic test. Rating vehicles simply by FMVSS 216 gives grossly misleading (both over and understated) injury rate results.

- The ten vehicle JRS dynamic tests presented in this paper are a sample of the results that are achieved with dynamic testing and the basis for the consumer rollover rating system. Three of the vehicles would receive "good" ratings, two with "acceptable", two with "marginal" and three "poor" ratings.

- When evaluating a rating system based solely on FMVSS 216, in comparison to dynamic testing, anomalies abound. The CRV is one such anomaly. The CRV emulates the rollover roof crush performance of vehicles like the XC-90 and the VW Jetta as shown in Figure 23.The CRV may be a styling-derived, partial and non-optimized implementation of a geometric roof improvement discussed and validated in our companion geometry paper.

- The proposed comprehensive ratings system would include a factored and weighted analysis by fatality rate and frequency of a vehicle's performance in all four major accident modes. This would provide an overall rating that consumers could use when purchasing a new or used vehicle.

ACKNOWLEDGEMENTS

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A SAFETY RATING FOR FAR-SIDE CRASHES

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ABSTRACT

A research team from Australia, Europe and the United States has conducted the research needed to provide a technology base for far-side crash protection. To date the findings are as follows: (1) in the USA and Australia there are large opportunities in far-side impact injury reduction, especially if safety features could mitigate injuries in both far-side planar impacts and rollovers, (2) a modified MADYMO human facet model was validated for use in evaluating far-side countermeasures, (3) either the THOR-NT or the WorldSID dummy would be satisfactory test devices for assessing far-side protection with minor modifications such as changing in the location of the chest instrumentation and (4) injury criteria and risk functions for use with WorldSID in far-side crashes have been documented. There is now a sufficient technology base so that far-side protection can be evaluated and rated by consumer information tests.

INTRODUCTION

An impediment to improved far-side protection has been the lack of a technical base to permit the evaluation of countermeasures. This deficiency has now been resolved by a collaborative international research project. The ARC Far-Side Impact Collaborative Research Project has been described by Fildes [2005]. It involved the assembly of a research team from industry, government and academia in Australia, Europe, and the United States. A list of the participating colleagues and organizations is included in the Acknowledgements Section.

The research involved the following projects:

- The definition of the far-side injury environment and the opportunities for injury reduction
- The development of representative test conditions and injury criteria for use with far-side test dummies
- The development and validation of computer human models for use in the evaluation of far-side countermeasures
- A matrix of sled tests of Post Mortem Human Subjects (PMHS) to determine occupant kinematics representative far-side crashes that produce injury and of the dummies available for the evaluation of far-side countermeasures.
- The assessment of the opportunities for injury reduction based on generic countermeasures

A technology base now exists to provide a far-side dummies, injury criteria, computer models, and test environments that can be used to evaluate countermeasures for far-side crash protection. This paper summarizes the research and documents its value to consumer information testing.

THE FAR-SIDE INJURY ENVIRONMENT

The National Highway Traffic Safety Administration (NHTSA) maintains the NASS/CDS database of vehicle crashes in the United States. The NASS/CDS is a stratified sample of light vehicles involved in highway crashes that were reported by the police and involved sufficient damage that one vehicle was towed from the crash scene.

In the NASS/CDS data query, far-side occupants in planar crashes were defined as drivers in vehicles with right side damage or right front passengers in vehicles with left side damage. Drivers in rollovers that were passenger side leading were classified as being in far-side rollovers. The converse was true for passengers.

Each NASS/CDS case contains a weighting factor that is used by the NHTSA to extrapolate the individual cases to the national numbers. The distributions to follow are based on the NASS/CDS weighted events.

Table 1 shows the annual distribution of MAIS 3 and greater injuries by belt use, crash direction and crash mode, using at least nine years of data for years prior to 2004 [Digges, 2006]. The data in Table 1 shows that about 43% of the MAIS 3+ injuries in side crashes and rollovers occur in far-side crashes. More than half of the MAIS 3+ injuries in rollover are in far-side rolls.

Table 1. Annual MAIS 3+ Injuries from NASS/CDS in Near-side and Far-side Crashes by Crash Type and Direction

Crash Type/ Belt Use	Planar	Roll
Far-side Belted	2,166	3,540
Far-side Unbelted	5,095	6,325
Far-side Total	7,261	9,865
Near-side Belted	7,360	3,532
Near-side Unbelted	6,714	5,551
Near-side Total	14,074	9,083
Near-side/Far-side Total	21,335	18,948
% Due to Far-side	34%	52%

An in-depth analysis of the crash environment for belted occupants in far-side crashes was presented in earlier papers [Gabler, SAE 2005 and ESV 2005]. The analysis indicated that for belted occupants with MAIS 3+ injuries, the 50% median crash severity was a lateral delta-V of 28 km/h and an extent of damage of 3.6 as measured by the CDC scale [SAE Standard J224, Collision Deformation Classification]. The most frequent damage area for seriously injured belted occupants was the front 2/3 of the vehicle (42%), followed by the rear 2/3 (21%). The most frequent principal direction of force (PDOF) was 60^{o} (60%), followed by 90^{o} (24%). The head and chest were the most frequently injured body regions, each at about 40% [Gabler 2008]. The injuring contacts that most frequently caused chest injury were the struck-side interior (23.6%), the belt or buckle (21.4%) and the seat back (20.9%) [Fildes, 2007]. A Harm analysis showed 30% of the Harm associated with side impact crashes occurred to the far side occupant and that this figure was reasonably consistent in both the US and Australia (Gabler, Firzharris, et al 2005).

MODELS AND DUMMYS FOR USE IN FAR-SIDE TESTS

The MADYMO human facet model was initially validated for the far-side crash condition by duplicating the far-side PMHS test reported by Fildes [2002]. The model validation was reported in a separate paper [Alonso, 2005]. The model was then used to evaluate occupant kinematics when subjected to a 28 km/h delta-V pulse that approximates the one produced by the IIHS barrier [Alonso, 2007]. The human facet model was also used to evaluate the consequence of variations in crash pulse and in generic countermeasures. The MADYMO human facet model was considered to be a good tool for assessing the influence of countermeasures on occupant kinematics in far-side crashes [Alonso 2007].

The accuracy of the seat belt to shoulder interaction for the MADYMO human facet model was evaluated by Douglas [ESV 2007 and AAAM 2007]. The shoulder complex of the model was modified to better duplicate the belt interaction. Validation of the model was based on low severity human volunteer tests and higher severity PMHS tests involving varying belt configurations and levels of pretension.

Initially, a range of current side impact test dummies (BioSID, BioSID_Mod, EuroSID1, and WorldSID were compared with a single PMHS test to evaluate their potential to represent a human in a far side crash [Fildes 2002, Bostrom 2003]. Subsequently, the MADYMO computer models of the existing adult side and frontal dummies were compared with the human facet model [Alonso, 2007]. The dummy models evaluated included the following: Hybrid III, Biosid, Eurosid 1, Eurosid 2 and SID2S. It was evident from the evaluation that none of the standard dummies possessed the kinematics to duplicate the motion observed in either the initial PMHS test or the MADYMO human facet model. Consequently, these dummies were eliminated from further testing. The WorldSID and the THOR-NT were subsequently selected as the best candidates for a far-side dummy. Sled testing indicated that the BioSID with a modified spine and shoulder unit did provide reasonable human-like kinematics [Fildes 2002, Bolstrom 2003]. However, this modified dummy was not a serious contender given its pure research status.

THE BIOMECHANICAL TEST PROGRAM

Under the Far Side Impact Collaborative Research Program, a series of PMHS tests was conducted by the research staff at The Medical College of

Wisconsin [Pintar, 2006, 2007]. The purpose of the PMHS tests was to assess the kinematics that needed to be reproduced in a dummy. The development of injury criteria was not a requirement. A test program that involved 18 different test configurations was conducted. Each test condition was run first with a PHMS and then the WorldSID and THOR-NT dummies were subjected to the same test condition. The test variations included test impact angle (60 and 90 degrees), test speed (11 and 30 km/h), shoulder belt type (inboard and outboard anchorages), center support (chest and shoulder load paths), shoulder belt tension, and shoulder belt anchorage location (high, low, mid and forward). All configurations included a center console support for the pelvis.

Three of the MCW tests involved different configurations of conventional three-point belts tested at 90 degrees. These configurations varied the height of the D-ring. In the low-position the D-ring was aligned with the top of the shoulder. In the mid-position, the D-ring was 90mm above the shoulder and the high-position it was 150mm above the shoulder.

The complete data for these tests is contained in the Stapp paper [Pintar 2007]. The y-z head trajectory plots are shown in the figures to follow.

Both the WorldSID and the THOR-NT response in far side impacts compared favorably to the PMHS responses. The WorldSID performed somewhat better in the 90deg tests while the THOR-NT was better in the 60deg tests. However, both dummies closely mimicked the head trajectory of the PMHS subjects in the testing conditions to which they were subjected. The greatest limitation of the dummies was the location of the chest deflection instrumentation. Some relocation of the chest instrumentation would be required in order to accurately measure this parameter in far-side crashes. The test results have been reported by Pintar [Pintar 2007] who concludes, "The THOR and WorldSID dummies demonstrate adequate biofidelity to develop countermeasures in this (far-side) crash mode". [Pintar 2007].

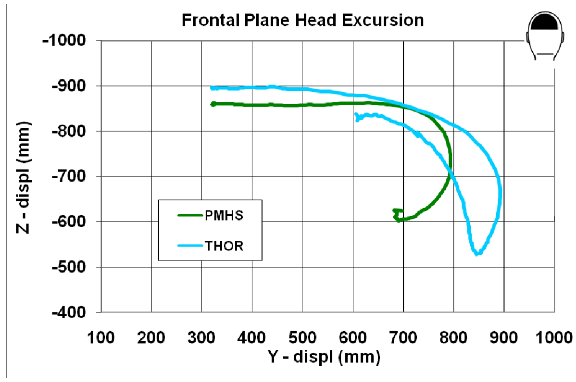

Figure 1. PMHS and THOR Far Side Sled Test (HS139) with Mid-Back Belt geometry @ 30km/h

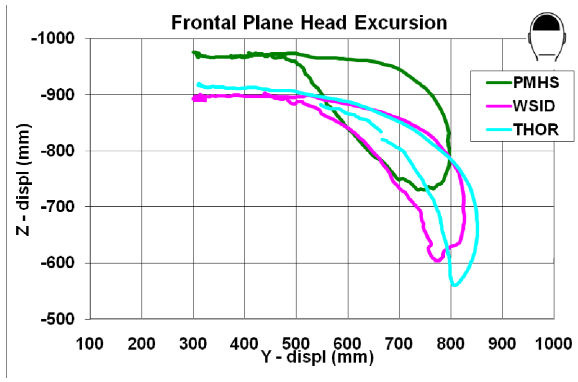

Figure 2. PMHS, WorldSID and THOR Far Side Sled Test (HS104) with Mid-Back Belt geometry and pretension @ 30km/h

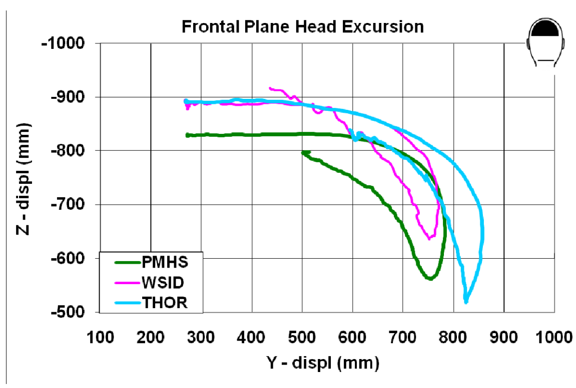

Figure 3. PMHS, WorldSID and THOR Far Side Sled Test (HS139) with Mid-Forward Belt geometry and pretension @ 30km/h

INJURY CRITERIA FOR FAR-SIDE DUMMY

The WorldSID Working Group has proposed injury criteria for use when the dummy is subjected to near-side impacts. Many of the injury measures are also applicable to far-side impacts. The WorldSID criteria applicable to far-side impacts have been summarized and criteria needed for the evaluation of far-side countermeasures has been added in a Task Report prepared for the project [Gibson and Morgan 2008]. The Task Report contains the available injury risk functions for the head and face, neck, spine, shoulder, thorax, abdomen, pelvis, lower extremities and upper extremities. It contains proposed injury risk curves for head, neck (skeletal), spine, chest, abdomen, pelvis, lower extremities and upper extremities.

One of the injury measures currently missing from most dummy measurements is the criteria for injury to the soft tissues of the neck. Of particular concern is the injury to the carotid artery from direct or induced loading by the shoulder belt or by other countermeasures. This issue has been attacked by teams from Medical College of Wisconsin, and Wake Forrest-Virginia Tech. The results have been reported in a series of papers [Stemper, IRCOBI 2005, J. Bio., 2005, Bio. Sci. Inst., 2005, IRCOBI 2006, J. Trauma, 2007, Annals Bio.Eng., 2007, J. Bio, 2007, and Gayzik, AAAM, 2006 and Bio. Sci. Inst., 2006].

KINEMATICS OF AVAILABLE DUMMIES

A review of the crash test films available at the NHTSA/FHWA Crash Film Library found only one documented test of a far-side crash. In this crash the crash direction was 90 degrees and the delta-V was approximately 15 km/h. The dummy slid out of the shoulder belt. Six far-side crashes were subsequently conducted and documented [Digges, 2001]. In this series of tests, angle of impact was 60 degrees and the delta-V was 40 km/h. The tests evaluated variations in shoulder belt tension and latch plate design. In all configurations, the Hybrid III dummy slid out of the shoulder belt. These tests suggested that additional countermeasures would be necessary to limit the excursion of the upper body.

Fildes [2002] reported on efforts to develop a dummy for use in far-side impacts. He found that existing dummies lacked the flexibility in the spine to duplicate the kinematics of a baseline PHMS test. In a later paper, Fildes reported better results based on limited testing of a BioSID dummy in which the spine had been replaced with a coil spring [Fildes 2003]. He recommended continuing research to develop a dummy and injury criteria so that countermeasures could be specified and evaluated.

CRASH TESTS WITH FAR-SIDE DUMMIES

Several vehicle crash tests have been reported in the literature that included both near and far-side dummies [Newland 2008]. The Newland study reported the result of 3 Moving Deformable Barrier (MDB)-to-car tests and 3 pole side impact tests. Four of the tests used the WorldSid as the far-side dummy. The other two tests used the bioSID. The MDB speeds in the tests were at 50 and 65 km/h. The impacts with the pole were at 32 km/h.

In all the tests, there was interaction between the two dummies. However, in all cases this later interaction had no influence on the injury measures from the near-side contact. The authors concluded that: "the presence of the adjacent dummy occupant seated on the non-struck side was observed to have no influence on the injury to the struck side dummy occupant resulting from intruding side structure".

In all six of the tests, the far-side dummy slid out of the shoulder belt. In two of the tests that involved a side impact with a pole, there was a head-to-head impact that produced a HIC in excess of 2000 on both dummies.

The authors recommended a minor change in the WorldSID to reduce the tendency of the belt to penetrate the cavity between the shoulder and thorax. This penetration occurs as the dummy begins to slip out of the shoulder belt.

MADYMO MODELING OF BELT GEOMETRY

To further evaluate the influence of belt geometry on the ability of the belt to retain the far-side occupant in a crash, the MADYMO Human Facet Model from TNO was used. This model had been validated against a single PMHS test and the results were published [Alonso 2007]. Further improvements in the model shoulder to belt interaction were accomplished, based on human volunteer testing at low severity far-side impacts and PMHS testing in more severe impacts [Douglas 2007]. As part of the present study, the model was validated against the three PMHS tests reported in an earlier section [Echemendia 2009]. The model was then applied to determine the effect of shoulder belt geometry and pretensioning on the response of a far-side dummy in tests typical of the NCAP and IIHS tests. The results show that the belt geometry that performed well in the PMHS tests continued to perform well in the consumer rating tests. The belt configurations that permitted the highest head excursion in the PHMS tests also permitted the highest head excursion in the consumer rating tests.

When using the Human Facet Model, the interaction between the seat belt and the shoulder area was known to be critical for accurate simulation. The

Human Facet Model was modified to better represent this shoulder area by adding rigid ellipsoids as previously reported by Douglas [2007]. A sphere with a radius of 0.053 m represented the shoulder and a sphere with a 0.045 m radius represented part of the upper arm near the shoulder. A Multi-body surface to Finite Element surface kinematic contact was used to describe the interaction between the safety belt and the ellipsoids representing the shoulder area.

The simulations of the PMHS tests showed that a seatbelt and the D-ring at a mid-height and back position resulted in the lowest head excursion. The PMHS test with the same belt position showed the same result. Simulations done with the D-ring at a mid-height and forward position and at a low-height and back position resulted in higher head excursions. In both of these cases, the belt slipped from the shoulder. The PMHS test with the D-ring at a mid-height and forward position also showed the belt slipping from the shoulder. An increased head excursion resulted.

These MADYMO results were generally similar when the 11km/h, 21km/h (IIHS) 24km/h (NCAP), 30km/h and 40km/h pulses were applied in the lateral direction. In simulations with the same lateral acceleration pulse but different belt geometry, results showed that the head excursion in the lateral direction ranged between 185 mm to 245 mm greater for the worst configuration when compared to the best belt configuration. The 11 km/h test was the source of the lower range and the 30 km/h test was the source of the higher range.

The largest difference in head excursion occurred in the 30 km/h tests and the Y-Z plots are shown in Figure 4.

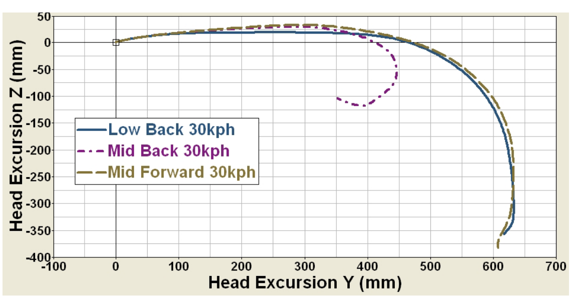

Figure 4. Human Facet Model Y-Z head excursion with three D-ring positions (tests @ 30km/h)

MODELING OF BELT PRETENSIONING

The same tests configurations were also simulated using a belt pretensioner. The belt pretensioner allowed 72 mm of belt retraction and it was activated 10 ms after time zero. The belt pretensioner did not prevent the belt from slipping from the shoulder in the mid-height and forward position and in the low-height and back position tests. It did reduce the head excursion in the lateral direction from 10 to 75 mm. The belt did not slip in the test with the D-ring at mid-height and back position similar to the test without pretensioning. It also reduced the head excursion by 61 to 74 mm. The largest difference in head excursion occurred in the 30 km/h tests and the Y-Z plots are shown in Figure 5.

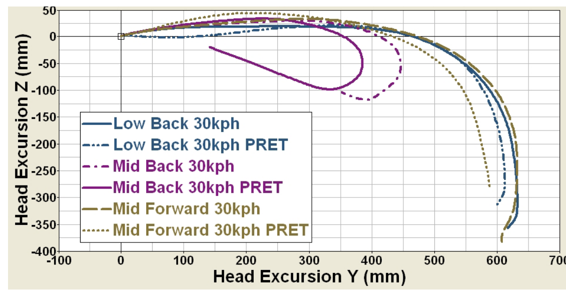

Figure 5. Human Facet Model Y-Z head excursion with three D-ring positions and with the use/no use of pretensioner (tests @ 30km/h)

These results show that while pretensioning helps reduce head excursion up to 75 mm, the appropriate location of the D-ring has a better benefit. According to these results the belt geometry is important to prevent the belt from slipping and to reduce head excursion.

A SAFETY RATING SCHEME

The THOR and WorldSID have both demonstrated good biofidelity in reproducing human kinematics in far-side crashes. The initial consumer information tests should utilize these validated capabilities and base the rating on head excursion. Ultimately, either dummy could be used to measure injury to all relevant body regions.

This strategy is similar to that employed in the initial standard FMVSS 213, “Child Restraint Systems”. The pass-fail criterion for the original 213 standard was based on head excursion.

The MADYMO modeling has shown that reduction of head excursion can be achieved by appropriate belt geometry and pretensioning. A key to reducing the head excursion is the retention of contact with the shoulder. If the occupant’s shoulder slips out of the belt the upper body is free to move laterally at increased velocity. The resulting impacts of upper body regions with intruding structure are likely to be increased in severity. In addition, undesirable loading of the abdominal region by the belt system may result. Retaining the occupant in the belt system should be beneficial in both far-side planar crashes and rollovers.

It is anticipated that the greatest benefit in controlling head lateral excursion will be a reduction of the severity of head contacts with intruding structures. This benefit provides another reason for using head excursion as the rating metric.

The NCAP test condition at a severity of about 25 km/h provides a reasonable crash environment for rating far-side protection. Figure 6 shows the distribution of occupants with MAIS 3+ head injuries. The figure shows a very sharp increase in frequency of head injuries in the range of 25 to 30 km/h lateral delta-V.

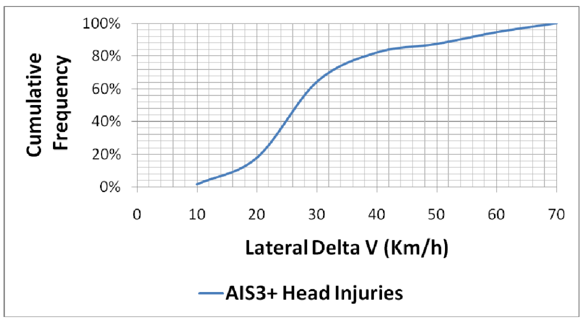

Figure 6. Distribution of occupants with AIS 3+ head injuries vs. lateral delta-V based on NASS/CDS 1993-2007

One consequence of limiting the lateral head excursion is an increase in the amount of intrusion that can be tolerated before a head strike occurs. This relationship is illustrated in Figure 7 [Echemendia 2009]. The figure is based on the maximum head excursion predicted by the MADYMO modeling of 30 km/h far-side crashes. The figure shows the clearance or interference between the head and the side structure as a function of the CDC extent of damage to the side of the vehicle. The head to side structure clearance for the best and worst belt configurations are plotted.

Figure 7 provides one possible basis for the far-side safety rating. The objective of the rating is to encourage designs to prevent a head impact with the intruding far-side structure. The more intrusion that can be tolerated before a head impact occurs, the higher the star rating should be. For the Taurus model, the belt systems that prevented the belt from slipping off the shoulder would tolerate an extent of damage CDC 4 before head contact occurred. If the dummy slipped out of the belt, the head strike would occur when damage reached a CDC of 3. Vehicles with less lateral occupant space might have different ratings for the same restraint configuration. If the restraint system prevents a head impact for an extent of damage CDC 5, the rating is 5 star. Lower star ratings would be assigned to correspond to the lower extent of damage permitted.

A moving deformable barrier side impact test at 65 km/h with WorldSID dummies in both the near-side and far-side front seat locations indicated that interaction between the dummies occurred at about 90 ms [Newland 2008]. In this test, the belt restraint system allowed the dummy to slip out of the belt. The interaction between the dummies was late enough so that it did not influence the interaction of the near-side dummy with the near-side countermeasures. The interaction was also late enough to permit the far-side dummy to slip out of the shoulder belt. However, the full range of head excursion was interrupted by the interaction of the two dummies. This impediment may require a modification to the star rating for belt systems that do not retain the far-side dummy. Additional crash testing should permit suitable refinements in the basic rating concept. Ultimately, head and chest injury measures could be used as is done in the NCAP ratings.

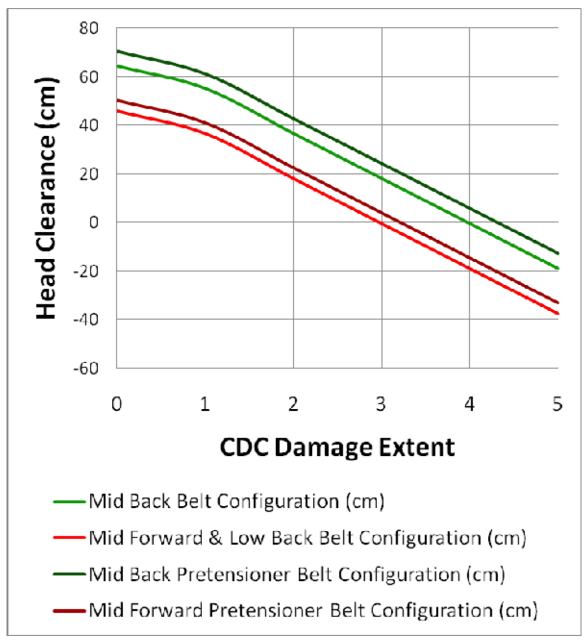

Figure 7. Clearance between the head and the intruding side structure in 30km/h MADYMO simulations for best and worst belt configuration on a Mid-Sized Vehicle (Ford Taurus)

DISCUSSION

Recent changes in US Federal Motor Vehicle Safety standards have introduced additional testing requirements intended to further improve side impact protection. These standards include tests with both 50% male and 5% female dummies in near side crashes with both a pole and a movable deformable barrier. The principal benefits from these tests are in near-side crash protection. There is no regulatory requirement for far-side protection based on dummy crash test performance.

At present, no agency conducts consumer information tests to evaluate far-side protection. As a result, there is little market incentive to incorporate technology that has been available for far-side protection. Earlier papers reported improved far-side protection in tests of new countermeasures including center air bags and four point belts [Bostrom 2005 and 2008]. Tests and modeling of conventional 3-point belts show that even current countermeasures can provide enhanced far-side protection at crash severities employed in near-side NCAP and IIHS tests.

An impediment to improved far-side protection has been the lack of a technical base to permit the evaluation of countermeasures. This deficiency has now been resolved by the research conducted by the Far Side Impact Collaborative Research Project and summarized in this paper.

The Project showed that the WorldSID and the THOR-NT both demonstrated a high degree of biofidelity in 18 tests that were representative of a large range of far-side crashes. Either dummy appears to be a satisfactory measuring device with regard to its kinematic response. However, changes in the location of the chest instrumentation would be required to obtain accurate readings of the maximum chest deflection. A shield for the shoulder joint is recommended for the WorldSID to prevent inaccurate kinematics after dummy slips out of the belt. The available injury risk functions to be used with the WorldSID have been collected from the literature and summarized in a report developed under the Project.

The MADYMO human facet model was shown to accurately duplicate the human kinematics when applied PMHS tests that simulate a far-side impacts. The modified MADYMO human facet model offers a basis for evaluating human kinematics when exposed to far-side impacts. Consequently, the model is useful for evaluating design variables in far-side safety systems.

The THOR and WorldSID have both demonstrated good biofidelity in reproducing human kinematics in far-side crashes. The initial consumer information tests should utilize these validated capabilities and base the rating on head excursion. Ultimately, the ratings could be based on HIC and other injury measurements that are possible on these advanced dummies.

The MADYMO models of the Hybrid III, Biosid, Eurosid 1, Eurosid 2 and SID2S were found to produce much less head excursion than observed in the PMHS tests that were used for model validation [Alonso 2007].

The MADYMO human facet model demonstrated that belt geometry and pretensioning can influence the performance of conventional three point belt systems as measured by a far-side dummy in a side NCAP or IIHS test.

Tests conducted in Australia have shown that the presence of a far-side dummy does not interfere with the side protection measurements made by the near-side dummy. However, there was interaction between the near-side and far-side dummies during the rebound of the near-side dummy. The interaction occurred well after the far-side dummy slipped out of the shoulder belt. Consequently, the ability of the belt system to restrain the far-side dummy could be determined by the test.

While most of this discussion has focused on consumer tests carried out in the US, it is also relevant for consumer tests in other parts of the world (eg; ANAP in Australia, EuroNCAP in Europe and JNCAP in Japan).

With the lack of any regulation in sight for ensuring improved far-side occupant protection, the inclusion of a WorldSID or THOR side impact test dummy on the non-struck side in current side impact tests is one option to address this shortfall.

CONCLUSIONS

All technical impediments to the crash test and evaluation of far-side countermeasures have now been removed by the research conducted under the Far Side Impact Collaborative Research Project.

There continue to be a large number of injuries that occur in far-side planar crashes and rollovers. A number of countermeasures have been demonstrated that could mitigate the injury producing environment of far-side crashes. There is at present no marketing incentive for introducing far-side countermeasures. The absence of regulatory and consumer information tests of far-side safety is now the major impediment to improved safety.

Either the WorldSID or the THOR-NT accurately mimic the kinematics of a human in far-side crashes of the severity used in SNCAP and IIHS tests.

Crash tests and modeling have shown that the retention of the far-side occupant could be improved by attention to the design of the existing 3-point belts. Consumer information tests to encourage these improvements would be a reasonable step to improve passenger safety in far-side crashes. On possibility for addressing this deficiency could be the inclusion of a WorldSID or THOR-NT test dummy in the far-side seating position when conducting a side impact consumer information test.

Crash tests have shown that the presence of a far-side dummy has no influence on the near-side dummy's measurement of injuries from the near-side contact.

Incorporation of a far-side dummy in SNCAP EuroNCAP, ANCAP, JNCAP and IIHS consumer information tests is a low cost and practical step to encourage safety improvements in far-side crashes.

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FLORIDA STANDARD FOR CRASHWORTHINESS AND SAFETY EVALUATION OF PARATRANSIT BUSES

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ABSTRACT

Research efforts on crashworthiness and safety assessment of paratransit buses were initiated and subsequently supported by the Florida Department of Transportation over the past ten years. They gradually evolved from computational mechanics feasibility studies using non-linear finite element (FE) methods to an industry standard implemented in the state of Florida in August 2007. Paratransit buses sold in Florida can now be evaluated for safety per the state standard based on either experimental testing or on rigorous computational mechanics analysis with validated FE models. Verification and validation (V&V) process is based on multi-scale laboratory testing including: material characterization, wall panel and connection tests, and testing of the entire bus. Validated FE models are subsequently used to provide a comprehensive safety assessment of the entire vehicle.

Two accident scenarios, identified as critical and dangerous by bus manufacturers and operators in the United States, are rollovers and side impacts. Rollover assessment for paratransit buses is based on a tilt table test. It was adopted for the Florida Standard from the UN-ECE Regulation 66 (R66) [1]. In addition, a side impact evaluation was introduced due to a significant segment of large SUVs and pickup trucks among all vehicles sold in the US. Penetration of the residual space is used as a failure criterion in both tests.

The computational track of the assessment program supported by the laboratory validation experiments is presented in the paper. A new method of safety margin assessment in the rollover test based on angular deformations of the bus cross section is introduced. The program has been well received and is now partially supported by the bus industry.

INTRODUCTION

Paratransit buses are defined as small buses that have a maximum capacity of 22 passengers. Production and use of paratransit buses has increased dramatically after 1990 since the Americans with Disabilities Act (ADA) [2] was introduced. The Act defines paratransit buses through their function as a complementary service for regularly scheduled routes. According to ADA - paratransit buses shall be able to transport at least two disabled passengers in their wheelchairs with the use of lifts to assist with the loading and unloading of disabled passengers. In addition to their smaller passenger capacity and different functions compared to a typical bus, paratransit buses also vary in their structure and construction methods. Unlike the monolithic construction of a larger bus, a paratransit bus is built in two distinct stages. First, the chassis and driver cab are produced by a major U.S. automotive manufacturer, most commonly: Ford or GM.
In the second stage, smaller companies (called body builders) construct and attach a complete passenger compartment (including all necessary interior equipment) to the chassis.

The Federal Motor Vehicle Safety Standards (FMVSS) define a bus as a motor vehicle with motive power, except a trailer, designed for carrying more than 10 passengers. The separate group standardized by FMVSS code pertains to the school buses. FMVSS does not recognize paratransit buses as a special group of vehicles. Per FMVSS a bus can be either a school bus or “other type of bus” and there is no exceptional treatment of paratransit buses by the standards [3]. The review of national and worldwide standards indicates that paratransit buses with their Gross Vehicle Weight (GVW) often exceeding 10,000 lb and specific way of two-step assembly process make them unique in the existing crashworthiness related regulations. Among US

standards, the FMVSS 208 [4] is the only code which provides specific requirements that can be applied exclusively to driver's seat in the bus.
At the same time production of passenger cars and school buses is strictly guided by several FMVSS standards and other Regulations: [5], [6], [7], [4], [8]. As a result, elderly and disabled passengers of paratransit buses, who need protection the most, are exposed to greater peril than passengers of other types of vehicles.

The Fatality Analysis Reporting System (FARS) developed by the National Highway Traffic Safety Administration (NHTSA) also does not distinguish a separate group of paratransit buses and places them in the group of "other buses". For that reason, detailed accident statistics regarding the performance of paratransit buses are scarce due to their common inclusion within a more general bus category in overall crash statistics. The communication with the Florida Department of Transportation (FDOT) representatives reveals that paratransit bus accidents do not happen too often. The FDOT indicates however, that the structural strength of paratransit buses is unpredictable and scattered due to different construction techniques and configurations used for the bus body structure. Structure of buses produced by the same manufacturer can differ from one another depending on the modifications required by local bus operators. Such modifications are rarely examined due to the high cost of experimental tests. Yet, the purchase of the new buses must be guided by both safety and economical reasons.

Figure 1. An example of a severe side impact accident between a mid size passenger car and a paratransit bus in Orange County, California (Courtesy: Orange County Register).

Figure 1 shows an illustration of a side impact accident involving a paratransit bus and a mid-size passenger vehicle. The fiberglass-based bus body was barely reinforced by the steel structure and turned out to be a very weak design solution in the impacted bus. As a result, the impact caused a disproportional damage to the bus.

Due to growing size of a paratransit fleet, the FDOT expressed its desire to increase passive safety for Florida paratransit buses in these types of accidents (side impact and rollover). The FDOT requested and sponsored the development of a new methodology that could be used for the bus testing and approval purposes. The main objective of the testing procedure was to indicate which buses are evidently weaker and more susceptible to excessive damage during the impacts. A multilevel research conducted under the FDOT sponsorship resulted in introduction of the crashworthiness assessment program [9] developed by the Crashworthiness and Impact Analysis Laboratory (CIAL). The program utilizes the experiences from computational mechanics studies, expertise of the FDOT, input from industry, and present and past regulations and standards.

This paper is a continuation of the work presented earlier at the EVS Conference in 2007, [10]. Ongoing research performed by CIAL resulted in the enhancement of the V&V procedures for bus rollover simulations, further development of the testing facility for rollover test approval, and in the development of new FE bus models. Multiple computational mechanics analyses and experimental tests performed by the CIAL and the FDOT resulted in valuable findings in the bus rollover safety research. The new safety lever rating system is presented in the paper as an outcome of the performed work.

CRASH AND SAFETY TESTING STANDARD

The Crash and Safety Testing Standard was initially described in the [9]. The complete standard [11] became a part of a former Florida Vehicle Procurement Program (FVPP), which has been recently transformed into the Transit-Research-Inspection-Procurement Services (TRIPS) Program [12]. The main goal of the standard is to assess the crashworthiness and safety of a paratransit bus either by experimental full-scale crash tests, or by the computational analysis using a FE method. At the first step both methods are considered equivalent and either one may be selected by the bus manufacturer for the bus approval.
If the computational method is chosen first and the result of the evaluation is negative, the evaluation can be repeated using the experimental method for the final approval.

The computational mechanics approval procedure is not necessarily the easier one but definitely more affordable for local companies producing paratransit buses. The computational analysis using the FE method requires a reliable and validated FE model. Testing and validation is an additional and necessary step in the numerical approach. The validity is assured thorough comparison of results from specially designed experimental tests with results from the FE simulations (refer to Figure 4 for details regarding validation procedure). The validated FE model is used to assess the crashworthiness and safety of the bus through: a side impact simulation and a rollover test simulation.

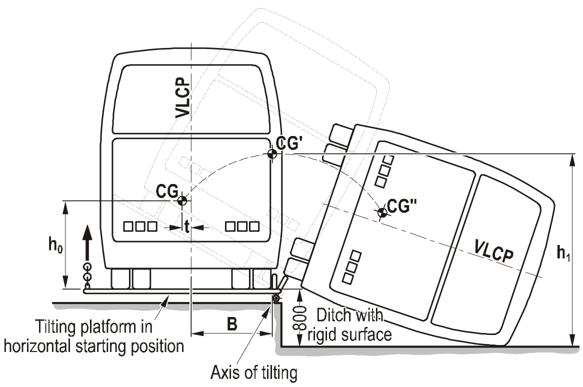

Figure 2. Rollover test setup according to ECE R66 [1].

In the rollover test a vehicle resting on a tilting platform is first quasi-statically rotated onto a weaker side. When the center of gravity reaches the highest, critical point, the rotation of the table is ceased and gravitation causes a free falling off the bus onto the ditch. Concrete flooring of the ditch is placed 800 mm beneath the tilt table horizontal position. Figure 2 shows three relevant positions in the rollover test: initial, critical and just before the contact with the ground.

A paratransit bus is considered to be crashworthy and safe if its residual space (see [1] and Figure 17 for the definition) is not compromised through either intrusion or projection during either actual or simulated tests [9], [1]. Passing results from both: side impact and rollover tests are required for an approval. Moreover, the experimental full-scale crash test is mandatory for further approval if the paratransit bus fails either of the computational analysis tests.

FE MODEL DEVELOPMENT

The FE model was developed for the LS-DYNA simulations [13]. The whole process was in the agreement with the Annex (number 9) to the R66 [1]. The document provided general rules for FE model development, requirements for software used for the approval and type of the results that shall be included in the report from the simulation.

The considered here FE model of a bus was developed in two distinct stages. During the first one, the FE model of the cutaway chassis was extracted from the public domain FE model of the Ford Econoline Van, developed by the National Crash Analysis Center (NCAC) at George Washington University [14]. Computer program LS-PrePost was used to delete redundant Econoline Van parts and LS-DYNA keyword definitions. Subsequently, various geometry modifications were applied to the FE model to convert the chassis from the van (E-150 equivalent) to the heavy duty E-450, based on the specifications used for the tested bus.

In the second stage three-dimensional AutoCAD model of the passenger compartment was built, based on the centerline dimensions of the profiles. Then the frame was translated to IGES (Initial Graphics Exchange Specification) format and imported to HyperMesh preprocessor to create FE mesh and other FE features. Subsequently skin surfaces and relevant elements of interior were developed and attached to the frame. All structural and some nonstructural components of the interior were included in the model to fully replicate mass distribution and inertia properties of the bus. Figure 3 shows the complete FE model of the bus-1 with the highlighted structural members of the body frame.

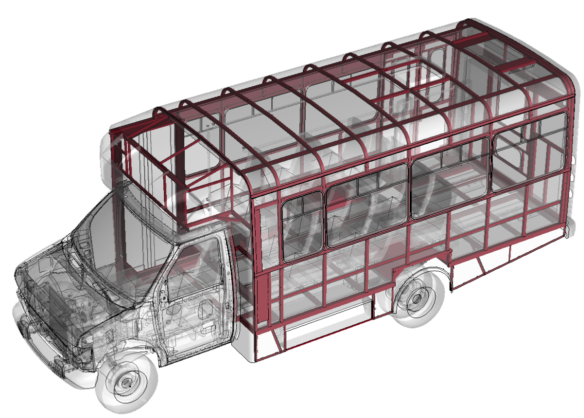

Figure 3. FE model of the bus-1 with highlighted structural members of the bus body.

All members of the frame were connected into one structure using 1-D SPOTWELD elements. The FE model development resulted in over 620,000 finite elements in the base model. Table 1 provides basic information about the bus FE model.

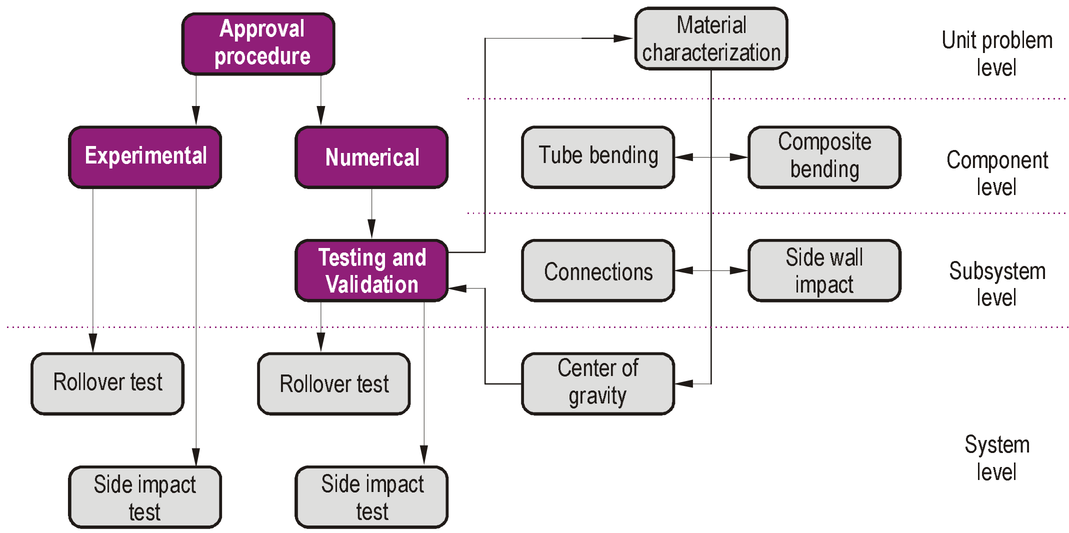

Figure 4. Approval procedure flowchart.

Table 1.
Finite Element model summary

Specification	Count	Specification	Count
elements	623,817	spotwelds	14,284
nodes	661,901	2-d elements	582,467
parts	349	3-d elements	41,342
1-d elements	8	-	-

The model is primarily built from shell elements. Thus, they determine the accuracy and the robustness of the solution. Type 2 shell elements are used as default in LS-DYNA and are frequently used in crashworthiness simulations. This under-integrated element requires about 2.5 times less CPU time than the other common element – type 16. The drawback of the element formulation 2 lays in possible development of nonphysical forms of deformations that produce zero strain and no stress – a process called hourglassing. The rollover simulation is considered to be long lasting (approximately 3 sec.) in comparison to the frontal or side impacts (about 0.2 sec). For that reason the model development process needs special precautions assuring stability of the solution.

The fully integrated type 16 shell element provides the most stable results with low level of spurious energies in the overall response. Thus it was used for the majority of the parts in the FE model of the bus.

The AUTOMATIC_SINGLE_SURFACE contact definition is recommended for crashworthiness simulations [15]. Although it is computationally expensive, it is also easy to implement for the complex models where multiple parts may interact (including self contact) during the simulation.

The concrete pad was modeled by RIGIDWALL option entry in the LS-DYNA. All elements from the bus were defined to be in the contact with that RIGIDWALL. The important parameter of the concrete pad in the rollover test is the friction coefficient between bus skin and concrete. From the experimentally determined range 0.57 to 0.7 [16] the most conservative was assumed – 0.7.

The initial simulations were starting at the unstable position of the bus. The bus was rotated so the CG was slightly beyond the vertical line drawn from the point of the bus rotation to enforce falling from the supporting table. Once the FE model was verified, subsequent simulations were starting with the FE bus model positioned just above the ground (to decrease the CPU time) and proper initial velocities were applied to the bus to reflect original conditions.

FE MODEL VERIFICATION

Introduced in 2006 the American Society of Mechanical Engineers (ASME) standard, titled "Guide for Certification and Validation in Computational Solid Mechanics" [17], defines verification as a process determining that computational model accurately represents the underlying mathematical model and its solution [17], [18]. In other words verification answers the question if equations are solved correctly [19]. Verification process is usually split into two independent parts – code verification and calculation verification. Verification of the code develops a confidence that solution algorithms are working correctly.

Calculation, solution or model verification builds the confidence that the solution of the mathematical model is accurate. It is the analyst's responsibility to perform this part of the verification where the major task is to estimate the amount of a numerical error [17]. Numerical solution error in FE simulations is mainly attributable to the discretization approximation. However, there are other multiple factors influencing correctness and stability of the solution. These quantities can be checked based on the energy balance during the whole process (see Figure 5). During the whole rollover all components defining the total energy should satisfy the principle of energy conservation. Obtained values of energy should also be verified against hand calculations as a first check of the simulation.

Based on the detailed description of the rollover kinematics in [20] an energy balance diagram was created as presented in Figure 5. The time instances marked in the diagram denote:

- t_1 – cantrail collision with the ground and development of plastic hinges in the bus cross sections,
- t_2 – waistrail collision with the ground,
- t_3 – critical structural deformations, plastic hinges stop working,
- t_4 – structural deformations end and elastic deformations are partially recovered,
- t_5 – end of the process.

The total energy applied to the structure during the impact is approximately equal to [1]:

$$E_T = 0.75 Mg\Delta h \quad \text{(1a).}$$

Where:
M – is the total mass of the bus. In the considered case, after inclusion mass of 13 passengers, it was equal to 5.2762 tons.
g – is the acceleration due to gravity and
Δh – is the vertical distance from the highest, unstable position of the bus CG to its final location (In this case it was equal to 1246.3 mm).
Thus the total energy applied to the bus is equal to:

$$E_T = 0.75 \cdot 5.2762 \cdot 9810 \cdot 1246.3 = 48.381 kJ \quad \text{(1b).}$$

The remaining 25 % of the potential energy is dissipated mostly to the ground and through damped vibrations [9]. In the investigated case, the numerically determined value of rigidwall (ground) energy was 18.083 kJ accounting for 28.03 % of the total energy. The maximum value of hourglass energy was 1.081 kJ, or 1.7 % of the total energy. The sliding energy was equal to 2.594 kJ, or 4.09 % of the total energy. The zero level of the potential energy was chosen to be at the final position of the CG. In the graph the energy falls below zero reference level, meaning that the CG of the bus at some point in the simulation is below its final position. It is due to the elastic rebound of the bus.

The energy balance and the grid convergence check should be the two major tasks performed in the verification of the FE model. The grid convergence study is difficult for such big models since subdivision of the elements would result in their overall number greater than 1 million. This check should be performed on the smaller, yet relevant components of the bus.

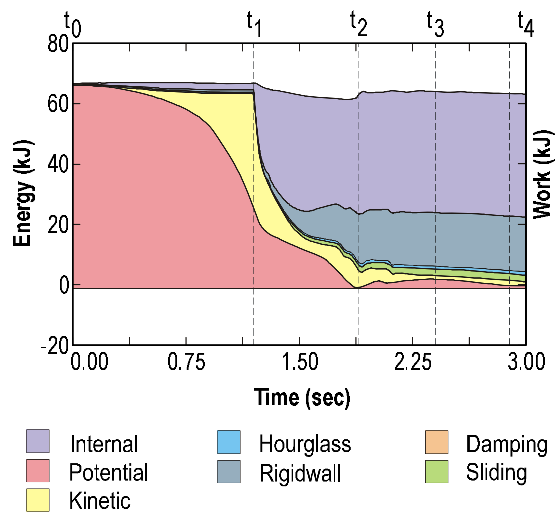

Figure 5. Energy balance for second rollover run transformed to other form.

FE MODEL VALIDATION

Roache, a pioneer of the V&V techniques, [21], describes the difference between verification and validation in his statement: "verification deals with mathematics whereas validation deals with physics". In simple words validation tells if we have chosen correct algorithms to solve our problem [19]. Technically the validation has the goal of assessing the predictive capability of the model for a given simulated event [17], [18]. It is performed by comparison of predicted results from FE simulations to experimental results from the same physical test. It is essential to select validation tests that are closely related to the event for which model is intended.

As advocated by the ASME standard "Guide for Verification and Validation in Computational Solid Mechanics" [18], the validation experiments of complex systems should have hierarchical character. Several tests were chosen as the most relevant for the bus structure and rollover test considered. Material characterization is at the lowest level of the validation hierarchy. Bending of steel tubes and skin composite samples can be categorized as testing at the component level. The bending of the connections and impact test on the side wall panels can be considered as tests on the subsystems of the structure. At the complete system level, a center of gravity (CG) check shall be performed. The proposed tests comprise only the required minimum that provide information about the behavior of the main structural components. Depending on time and budget constraints, additional tests shall be conducted for better results and increased model reliability. The most desirable then would be the testing of connectors (adhesive, welds and bolts).

Bending of Structural Tubes

Three buses were investigated in this research project. They are coded as bus-1 to bus-3. However, the numerical results are presented for the bus-1 exclusively.

The main structural elements in the considered paratransit buses are usually build from square tubes. Their dimensions and results from the steel tension testing for all three buses are shown in Table 2. According to [22] (Table B4.1) for uniformly compressed flanges of rectangular box and hollow structural sections subject to bending, the limiting ratios for compact and noncompact profiles respectively are calculated using the formulas:

$$\lambda_p = 1.12\sqrt{\frac{E}{\sigma_y}} \qquad \lambda_r = 1.40\sqrt{\frac{E}{\sigma_y}} \tag{2}$$

The HSS 1.5 in x 1.5 in x 18 ga tubes, used in the bus-1, are in the intermediate level and two other cross sections are in the compact regions.

A four point bending test was selected as the direct measure of the strength of the tubes and the validation of the model. The testing apparatus for the four point bending is shown in Figure 6. The distance between the external (moveable) supports is equal to 900mm and 300 mm between internal supports. The internal supports were connected to the grip through the hinge. The diameter of supports was equal to 30 mm. The INSTRON 8802 testing machine with FastTrack software was used for the tests. The displacement was applied with the rate of 20 mm/min. The bridge tensometer ESAM Traveller PLUS was used for the test together with the LVDT's RC20-100-G [23]. The displacement of the bottom (moveable) traverse is denoted as d_0. Additionally deflection of the beam in points d_1 and d_3 (under the internal supports) and d_2 (middle of the beam) were recorded.

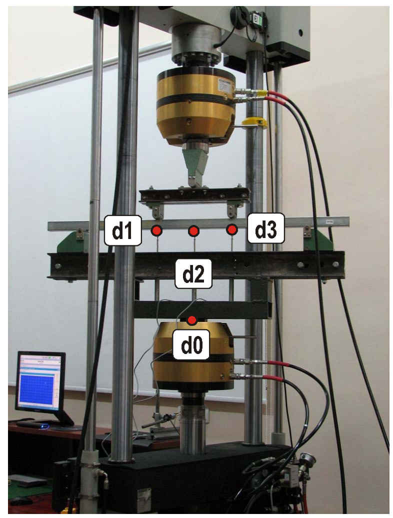

Figure 6. Testing apparatus for four point bending test.

The quantitative results of the tests are shown in Figure 7. For HSS 1.5 in x 1.5 in x 18 ga (bus-1) tubes local buckling was the reason of reaching ultimate strength. Although the cross section in the case of HSS 1.5inx1.5inx16ga (bus-1) tubes is compact the local buckling also occurred. In the case of the bus-3 tubes the cross section was considered as compact and with λ low enough the local buckling was not present. Only global deformations were present in this instance as shown at the bottom three specimens in Figure 7.

Figure 7. Deformed tubes as a result of the four point bending tests.

Table 2.
Mechanical properties of tested steel

Steel source	Tubes dimensions	Young's modulus $E(MPa)$	Yield stress $\sigma_y\,(MPa)$	Ultimate strain $\varepsilon_u\,(-)$	Cross section classification
bus-1	1.5 in x 1.5 in x 18 ga	171300	281.1	0.36	intermediate
bus-2	1.5 in x 1.5 in x 16 ga	222400	359.0	0.25	compact
bus-3	1.0 in x 1.0 in x 16 ga	207300	389.4	0.18	compact

Figure 8 contains averaged curves presenting the exerted load plotted against the displacement of the point d_0 for three types of tested tubes. Although the 1.5 in x 1.5 in x 18 ga tube used in the bus-1 has a greater cross-sectional area than 1.0 in x 1.0 in x 16 ga, bus-3 tube, the obtained ultimate strength is only 15% greater than the ultimate strength of bus-3 tubes. At the same time it is 75% weaker than 1.5 in x 1.5 in x 16 ga, bus-2 tube.

The same test for the bus-1 was also simulated using the LS-DYNA software. The load – displacement curve from the FE analysis is also shown in Figure 8. The ultimate load obtained in the simulation was 5.012 kN which results in 1.8 % of the relative error when compared with the experimental value of 5.108 kN.

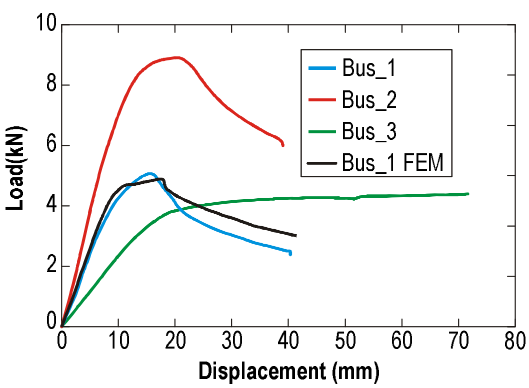

Figure 8. Load-displacement characteristics for tubes tested in bending.

Bending of the Connections

The bus body is constructed by first assembling the major components (floor, sidewalls, backwall, roof) individually and then welding and/or bolting them together. This process creates major connections between the subsections. Dynamic performance of these connections does not only depend on the material properties but even more significantly of the selected connection design which is affected by the bus assembly process.

Figure 9 shows location of the wall-to-floor WF (1) and roof-to-wall RW (2) connections selected for connection testing.

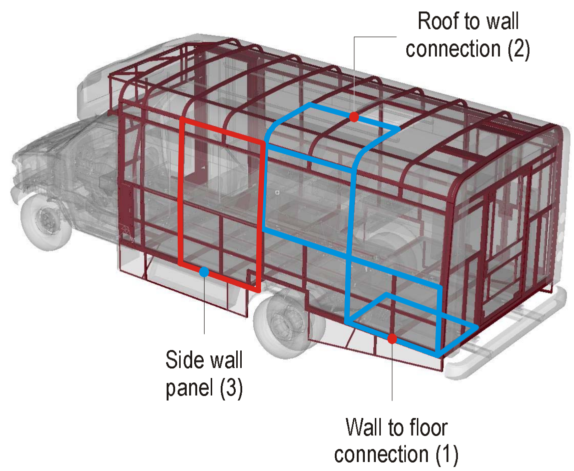

Figure 9. Location of components for connection testing in the bus structure.

Representative samples of the connections were obtained from the manufacturer for the study of the RW and WF connections. Connections are tested in bending where one side is clamped and the other is pulled quasi-statically to decrease the angle between both sides. The testing apparatus shown in Figure 10 was designed to measure the resistance response of the connections.

Figure 10. RW connection without skin fixed for bending testing.

It allowed for data acquisition of a rotation angle of the connection as a function of the force (or: equivalent moment) applied. A large concrete block is used as a base and the lower part of the test section is fixed by butting against this block and then being bolted to the floor through the aluminum I-beams. Two hand winches are attached to either side of the block and connected to the test section with an in-line Strainsert tension link rated at 17,793 N (4,000 lbs) full scale to the load application point. Displacement was measured using two SpaceAge Control D62-60-82E1 wire-type position transducers for each side (North and South), vertically spaced on the concrete block (d_1, d_2, d_3, d_4), but connected to the same point on the test section to provide the vertical and horizontal displacement using triangulation technique. The data recorded included the load and two displacements for each side using a SCXI DAQ data acquisition system and LabVIEW 8.2 software. The load application was quasi-static and keeping the displacement of each side almost equal.

Figure 11 and Figure 12 present characteristic curves obtained for two connections – WF and RW respectively. Together with the experimental results the curves from corresponding LS-DYNA simulations are shown. The FE simulations were conducted for two cases of different tubes thickness – 100 % of nominal and 93 % of nominal thickness, which was equal to the measured thickness of the walls.

In the case of the WF connection the deformation of 18 deg is equivalent to the failure of the bus (in terms of the residual space) in the rollover test. For the simulation of the test with reduced thickness the bending moment reached 446.4 Nm whereas corresponding value in the experiment was equal to 451.4 Nm. The relative error was only 1.1 %.
In the RW connection the angle of the deformation of 39 deg is equivalent to intrusion into the residual space during the rollover test. The value of the bending moment at that deformation level in the experiment was equal to 371.1 Nm. For the FE model with reduced thickness the moment was 351.2 Nm. It resulted in the relative error of 5.3 %.

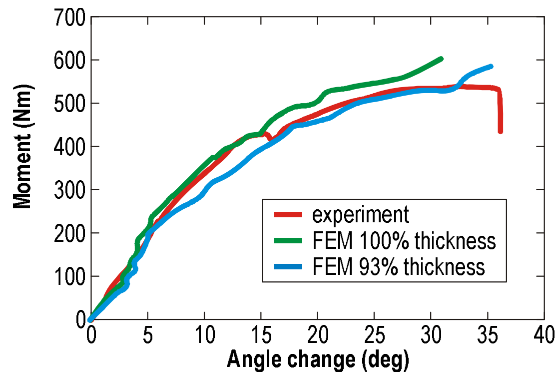

Figure 11. Comparison of results for WF connection without the skin.

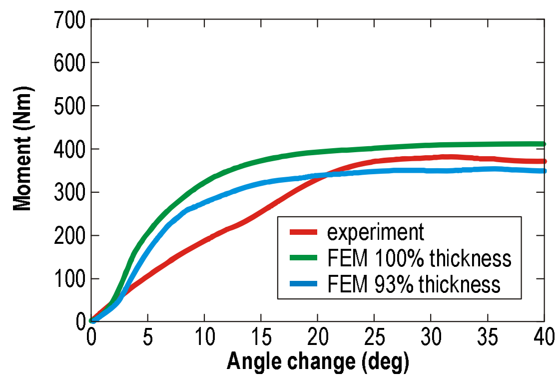

Figure 12. Comparison of results for RW connection without the skin.

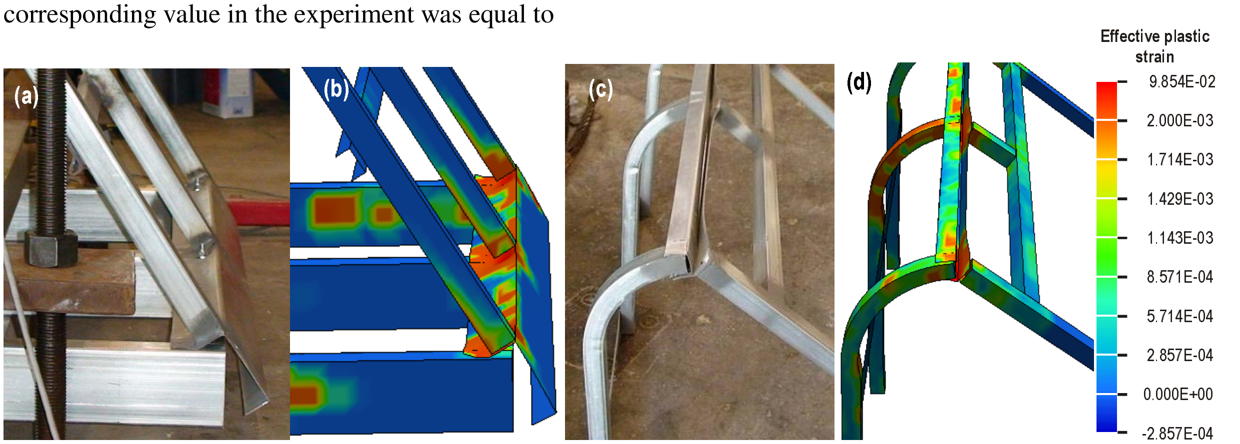

Figure 13. Deformations in the tested skinless connections from bus-1 (a) WF connection (b) FE model of WF connection (c) RW connection (d) FE of RW connection.

Figure 13 shows deformations in the connections obtained in the experiments and corresponding deformations in the FE simulations. The figures reveal poor design of the connections. The major deformations occurred not in the structural beams but in the transition members like C-channel in the WF connection and L-shape in the RW connection. In order to increase the strength, the elements should have additional welds and/or bolts preventing unnecessary and excessive deformation.

Side Wall Impact Test

A dynamic impact test on the side wall panel was developed for additional model validation. Location of the side wall panel used for the testing in the bus structure is shown in Figure 9 under the number 3. The panel is cut off from the wall and extends from the cantrail to the level of the floor. Its width spans two major vertical beams (which are included in the panel) thus both dimensions (height and width) differ for every single bus model. Initial conditions for the test are shown in Figure 14.

The panel is resting horizontally on raised tubular supports with 150 mm diameter. The two supports are at adjustable distance which in this case was 1600 mm. The impacting device is comprised of impacting square tube, perpendicular rectangular arms and crossing rectangular beams. It is mounted to the supporting beams in the way that allows free rotation of the device. All elements are made of steel. The impacting arm is suspended on the steel wire and connected to the hand winch allowing for raising the arm. In the test the hammer is dropped from the pre-calculated height assuring reasonable amount of the deflection imposed by the impact. In this case the initial height was 700 mm. The total mass of the impacting device is 132.4 kg. The location of the impact zone is selected to be below the waistrail level which is close to the middle of the panel. Due to the short duration of the event only the final results of the experiment are captured. The character of deformation and maximum deflection are recorded and then used for comparison with numerical results.

In the design of the side wall used for the test the waistrail beam was continuous throughout the length of the bus and the vertical beams were welded to it at the top and the bottom. Discontinuity of the vertical pillars resulted in the excessive local deformations in the waistrail beam as shown in Figure 15 b. Figure 15 a shows corresponding deformations in the FE simulation for comparison.

The basic model with two finite elements across the beam width was not capable of capturing such severe deformation. The mesh density had to be increased to fully reflect real deformation pattern. With the increased mesh density, obtained deflection in the FE simulation was equal to 298.8 mm. In the experiment the deflection was 312.0 mm which gave the relative error for the FE simulation of 4.2 %. Such design should be avoided in the bus structure since the capacity of it depends only on the strength of the single thin wall of the waistrail beam.

In the research another design was checked where the waistrail beam was discontinuous and was welded to the continuous vertical columns in the wall structure. The design was subjected to the same loading conditions and Figure 15 c shows local deformations in it. The deformation was less dramatic and the overall deflection of the panel in the test was reduced to 81.1 mm. It is equal to 72.8 % reduction of the displacements.

Summary of the V&V program

The FE model of the bus was verified for numerical errors and the instabilities in the solution. The energy balance was used to prove sanity of the calculations and compare obtained values of the total energy, and energy dissipated into the ground, with empirically expected values. The non-physical hourglass energy was shown to stay below 5 % of the total. The same condition applies to the sliding interface energy.

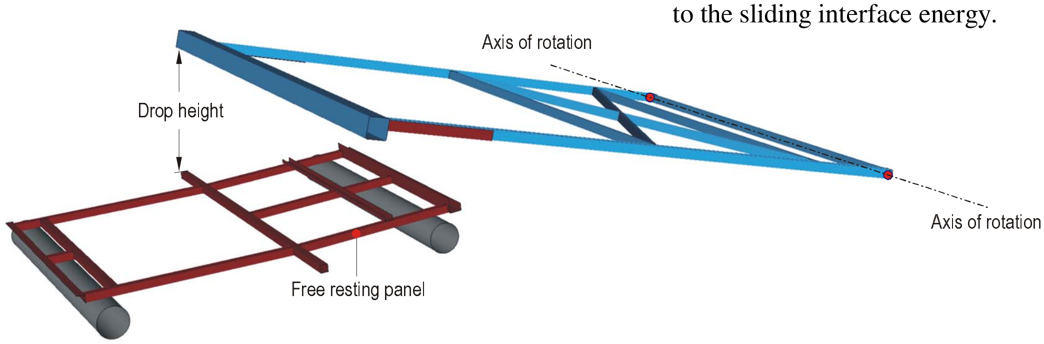

Figure 14. The FE model of the side wall panel without the skin.

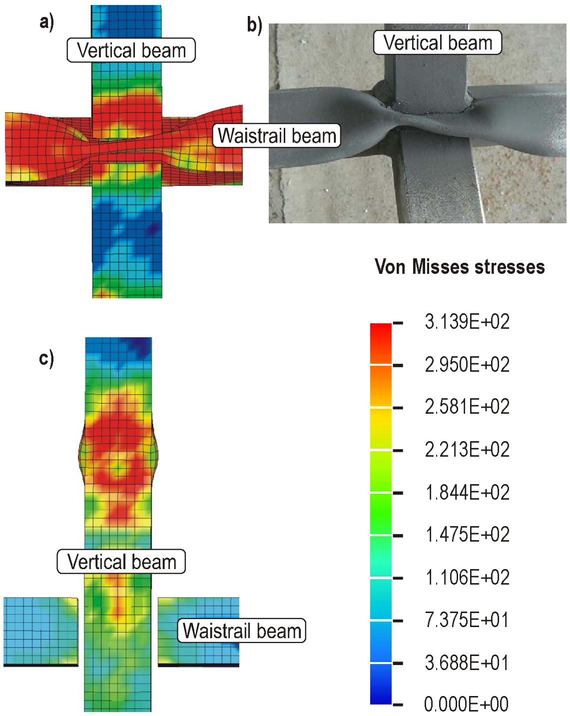

Figure 15. Local deformations in the tested panels.

The number of elements on the edge of the main tube in the entire bus model was increased to 4 after the side wall panel tests. Still it is lower than 8 elements used in the FE simulation of the side wall impact test.

Other factors also contribute substantially to the overall response of the bus in the rollover test. The bonding strength of the adhesive used between the skin and the frame is one of them. Yet, the most crucial, steel cage can be assumed to be fully validated.

SIMULATIONS OF THE ROLLOVER TEST

The verified and validated FE model of the bus was subsequently used in the simulations of the rollover standardized test. A follow up case study was performed on the FE model that answered several theoretical and technical questions regarding the bus rollover. For the purpose of this research a new measure quantifying safety margin in the rollover test was introduced. The current UN-ECE Regulation 66 does not define any quantitative measure to assess extent of the deformation and the safety margin in the rollover test. The pass/fail decision is the only outcome from the test procedure per R66. The proposed deformation index DI_α can be very advantageous for comparative studies in rollover simulations. The common measure of the vehicle response in the accident – intrusion may be hard to interpret in the case of rollover since deformation in actual accidents often includes twisted patterns. Moreover, the width of the residual space varies with the height. Since the cross-section of the bus deforms primarily in several vulnerable spots through plastic hinges (PH), the rest of the structure deforms considerably less. It is more innate to measure the angular deformations at the expected plastic hinges. Figure 16 presents a cross section of the bus with the numbered angles measured at the hypothetical PHs. These are:

- α_1, α_6 – wall to floor connections angles,
- α_2, α_5 – waistrail angles,
- α_3, α_4 – roof to wall connections angles.

These angles are used to measure one deformation index DI_α. This index, together with the pass/fail grade, can provide a more descriptive assessment of the bus structure deformation level in the rollover test. The deformation index DI_α can be defined as a function of two major angles:

$$DI_\alpha = f\left(\Delta\alpha_1, \Delta\alpha_2\right) \quad (3).$$

Where:
$\Delta\alpha_1, \Delta\alpha_2$ – are the changes in the respective angles due to the rollover impact deformations at the side impacting the ground.

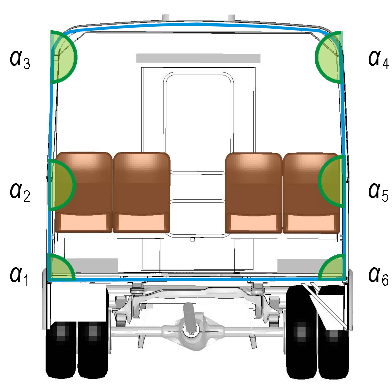

Figure 16. Angles of interest in the bus cross section.

Figure 17 shows the geometry of the bus cross section in an arbitrary failure mode. Deformation angles are combined with the definitions of the residual space to lead to the derivation of the approximate expression for DI_α.

The distances w_1, w_2 from Figure 17 are defined as follows:

$$w_1 = l \cdot \tan(\Delta\alpha_1) \quad (4).$$

$$w_2 = (h - l) \cdot \tan(\Delta\alpha_2) \quad (5).$$

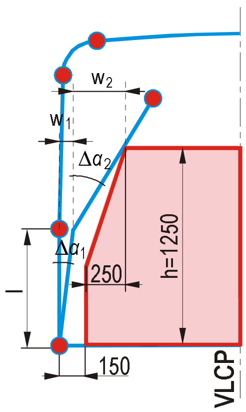

Figure 17. Geometry of the failure mode.

Their sum for the critical state is equal to *d*:

$$w_1 + w_2 = d = 150 + 250 = 400mm \quad (6).$$

Substituting w_1 *and* w_2 from Equations 4 and 5 yields:

$$l \cdot \tan(\Delta\alpha_1) + (h - l) \cdot \tan(\Delta\alpha_2) = d \quad (7).$$

or:

$$\frac{l}{d} \cdot \tan(\Delta\alpha_1) + \frac{(h - l)}{d} \cdot \tan(\Delta\alpha_2) = 1 \quad (8).$$

Thus the deformation index DI_α can be defined as:

$$DI_\alpha = \frac{l}{d} \cdot \tan(\Delta\alpha_1) + \frac{(h - l)}{d} \cdot \tan(\Delta\alpha_2) \quad (9).$$

or with numerical values:

$$DI_\alpha = \frac{l}{400} \cdot \tan(\Delta\alpha_1) + \frac{(1250 - l)}{400} \cdot \tan(\Delta\alpha_2) \quad (10).$$

The formula seem to be complicated at the first glance but in fact only three quantities need to be measured in order to determine the safety level of the bus. Consider three basic cases of failure configuration for a modeled bus with the angle changes given in Table 3. The distance *l* in this case was equal to 788mm. Equation 10 becomes:

$$DI_\alpha = \frac{788}{400} \cdot \tan(\Delta\alpha_1) + \frac{(1250 - 788)}{400} \cdot \tan(\Delta\alpha_2) \quad (11a).$$

$$DI_\alpha = 1.97 \cdot \tan(\Delta\alpha_1) + 1.155 \cdot \tan(\Delta\alpha_2) \quad (11b).$$

Table 3 shows computation of the deformation indices for the three simple failure modes of the bus cross section. It is assumed that the deformations occur only in the PHs and the deformation of the rest of the structure is negligible. It needs to be pointed out that the $\Delta\alpha_2$ in the formula is a sum of the angle changes α_1 and α_2, and the absolute value of angle changes are used in the formula.

Table 3.
Comparison of the deformation index for three simple failure modes of the bus cross section in the rollover test

Specification	*Failure mode I*	*Failure mode II*	*Failure mode III*
α_1	18.0	0	10.0
α_2	0.0	39	19.0
DI_α	1.015	0.935	0.988

DI_α index can be effectively used to assess a safety margin. The structure is considered inacceptable, or it is assigned one rating star, when DI_α is equal or greater than 1. It indicates an intrusion into the residual space and the bus fails the rollover test according to the UN-ECE Regulation 66.
The maximum grade of five stars is assigned to strong structures with 60 % safety margin with the corresponding $DI_\alpha = 0.4$. Other ratings for the DI_α are proposed in Table 4.

Table 4.
Rating ranges for the proposed deformation index DI_α

Range	*Descriptive strength rating*	*Star rating*
$DI_\alpha < 0.4$	strong	*****
$0.4 \le DI_\alpha < 0.6$	intermediate	****
$0.6 \le DI_\alpha < 0.8$	acceptable	***
$0.8 \le DI_\alpha < 1$	poor	**
$DI_\alpha \ge 1$	inacceptable	*

Influence of the Skin Layers

The influence of the skin layers on the bus rollover performance was checked. R66 requires testing the strength of the superstructure in the rollover test. The superstructure is defined as a part of the bus structure that contributes to the bus performance in the rollover test. Often the skin part is ignored in the FE model to simplify the modeling. Although this procedure may seem effective and trustworthy for long buses it appears to be vague for the shorter vehicles. Whenever the thin walled structure (like bus shell) is in torsion then that thin layer of the skin really matters as far as strength is considered.

Figure 18 shows the deformed cross section of the buses with- (a) and with-out (b) the skin on it. In the case (a) the residual space is not compromised. Computed for this case the deformation index was equal to 0.69, what gives the bus “three stars” in the rating system introduced in Table 4. In the case (b) the results are completely different. The residual space is visibly penetrated.

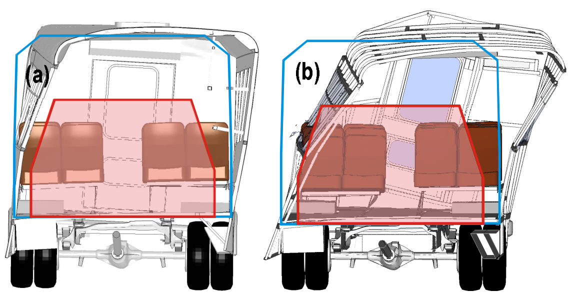

Figure 18. Deformation of the bus body in rollover simulation (a) bus with the skin (b) bus without the skin

Table 5.
Comparison of angular deformations in the models with (model 1) and without the skin (model 2)

angle	initial stage	angle change 1	angle change 2
α_1	90	-11.5	-21.8
α_2	177.6	-2.5	-16.3
α_3	180.0	19.8	34.1
α_4	180.0	-7.9	-41.7
α_5	177.5	-0.2	2.2
α_6	90	7.5	14.8
$DI\alpha$	-	0.69	1.31

The angular deformations in the plastic hinges presented in Table 5 differ substantially. The deformation index for the model without the skin is 1.31, meaning, it increased 89.8 %. It becomes obvious that the skin sheets contribute substantially to the rollover resistance of the paratransit buses.

Initial Conditions Sensitivity

Sensitivity of the results due to variations of initial conditions has been checked. The repeatability of the results from a full scale rollover test according to R66 is sometimes questioned by engineering community in the US [24]. FE analysis is an efficient method to check that hypothesis. In the simulation presented previously the bus hits the ground uniformly along the entire cantrail length. Two additional cases were investigated. In the first the bus was rotated 3 deg with respect to its yaw axis in such a way that the front part of the bus is closer to the ground (negative yaw angle) – model “F”. This way, the more vulnerable frontal part of the bus will take the first impact. Subsequently, a positive angle of 3 deg was applied and the bus had its first impact to the ground at the the back cantrail corner – model “R”. Such apparently negligible disturbance may easily happen in the real world test where many factors (e.g. behavior of the tire during the test) are of a rather unpredictable nature.

Table 6.
Comparison of angular deformations in the models with different initial conditions

angle	initial stage	angle change F	angle change R
α_1	90	-16.1	-13.2
α_2	177.6	-1.1	-1.2
α_3	180.0	20.4	14.2
α_4	180.0	-12.4	-9.0
α_5	177.6	-0.3	-0.3
α_6	90	14.6	6.2
$DI\alpha$	-	0.93	0.76

Table 6 shows the values of the angle changes compared for both cases considered. In the first case the DI_α increased from the initial 0.69 (base model) to 0.93 (34.7 %), and in the second case it increased to 0.76 (10.1 %). This study shows that rollover tests are sensitive to variations in the initial conditions. Different structure stiffness of the front and rear end of the paratransit bus may cause significant discrepancies in real tests depending on which part of the bus will touch the ground first.

Influence of the Strain Rate Effect

The question about the importance of strain rate effect in the structural steel for the rollover accidents was raised among the bus rollover testing community too [25].

Additional FE bus model was virtually tested to investigate the strain rate effect on rollover test results. In the modified base model - the strain rate effects were not accounted for (model "NO-CP"). The only difference between the base model and "NO-CP" model is that the *C* and *p* parameters in the Cowper-Symonds strain rate dependency model were turned off. The set of parameters: C=80 and p=4 was used in the base model [14]. No dramatic difference in the response of the bus was noticed in the simulations. Table 7 shows angle changes for these models. Yet, the DI_{α} difference for the models was 7.2 %.

Table 7.
Comparison of angular deformations in the models with different Cowper Symonds parameters and different mesh densities

angle	initial stage	angle change	angle change NO-CP
α_1	90	-11.5	-9.3
α_2	177.6	-2.5	-10.7
α_3	180.0	19.8	17.7
α_4	180.0	-7.9	-10.6
α_5	177.6	-0.3	-0.5
α_6	90	7.5	11.9
DI_{α}	-	0.69	0.74

CONCLUSIONS AND FUTURE WORK

The current status of the research on the Florida standard for crashworthiness and safety evaluation of paratransit buses was presented. Verification and validation methodology for the Finite Element simulations of standardized rollover test are introduced. Computational mechanics analyses were verified by the energy balance tracking and complementary hand calculations. The numerical results were compared to the results from the experiments on different levels of the validation hierarchy. Good correlation of results was obtained for each case. Computer simulations provided answers to several technical questions. In particular it was shown that:

- The bus skin is an essential element of the FE model. It significantly contributes to the overall strength of the bus.
- The rollover test according to R66 [1] may be sensitive to the disturbance of initial conditions depending on the bus structure.
- Negligence of the strain rate effect in the rollover test results in about 7% of the difference in the response of the bus.

Also the deformation index and the star rating system are proposed to assess safety margin in the rollover test.

The first full scale rollover tests on paratransit buses in the state of Florida was performed by CIAL and FDOT in December 2008. It is planned to provide in the future comparative results from these tests along with results from the corresponding numerical simulations.

ACKNOWLEDNGEMENTS

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REAR OCCUPANT PROTECTION JNCAP TEST

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Abstract

In June of 2008, it became mandatory in Japan for rear seat occupants to wear a seat belt under the new Road Traffic Act. Rear seat occupants involved in frontal collision traffic accidents in Japan are mainly women. Considering this situation, we will start to evaluate rear seat occupant safety performance in frontal collision tests using a Hybrid III AF05 dummy. The evaluation includes not only this dynamic collision test but also the usability of the rear seatbelt and seatbelt reminder for passengers including those in the rear seat, which is not mandated by the law. We will show in detail the methods for rear occupant protection in a frontal collision and the ease of use of rear seatbelt, which will be the first introduction worldwide by JNCAP.

1. Background of introduction of this evaluation

The number of traffic fatalities in the year 2008 in Japan were dramatically reduce to 5,155 victims from the levels of around 10,000 10 years ago, This nearly met the Japanese government target established in 2003 which called for the reduction of traffic fatalities to under 5,000 victims by 2012. However, a new target was established in January of 2009 to reduce the number of victims to under 2,500 within 10 years. Under these circumstances, the Japan New Car Assessments Program (JNCAP) has the duty to contribute to the reduction of traffic accident victims.

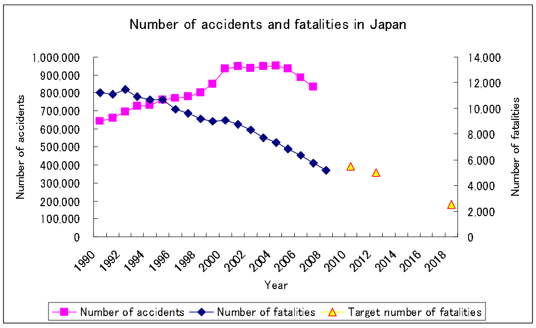

Figure 1. Number of accidents and fatalities in Japan

Since the JNCAP introduced the Full-wrap frontal collision test and Braking performance test in 1995, a Side collision test was added in 1999, followed by the Offset frontal collision test in 2000 enhancing the overall collision safety performance evaluation for driver and front passenger. But the rear seat passenger safety performance was not evaluated by the JNCAP. With the Road Traffic Act revision of 2008, making rear seatbelts mandatory, the rate has begun to improve (road : 8.8% → 30.8%; Expressway : 13.5% → 62.5%; see Figs. 2 and 3). Under these circumstances, the safety assessment for rear occupants with seat belts now has increasing significance.

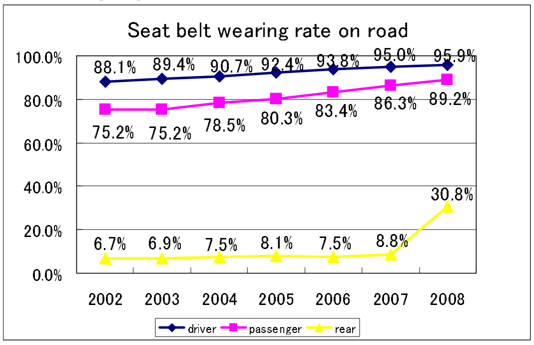

Figure 2. Seat belt wearing rate on road

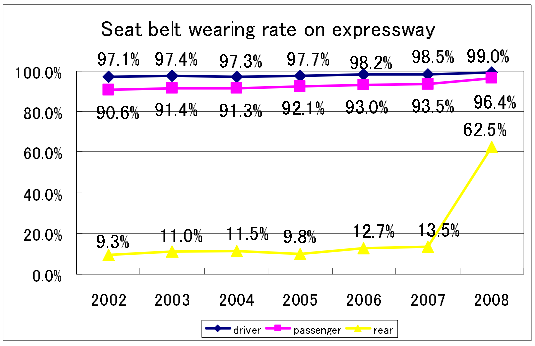

Figure 3. Seat belt wearing rate on expressway

In addition, the rear seat belt is less convenient to use than that of the front seat. According to Anders, Lee[4] and Motoki[5], although a Seat Belt Reminder (SBR) serves to increase the seat belt wearing rate, it is rarely installed for rear seats in Japan. Thus, the JNCAP decided to introduce 1) dynamic evaluation for rear seat passengers to improve protection performance, 2) evaluation of usability performance of the rear seat belt to improve the belt fastening rate, and 3) evaluation of SBR for all passenger seats by JNCAP.

2. Study of evaluation method for rear seat occupant protection performance

(1) Evaluation of occupants protection performance during crash - introduction in 2009 FY

1) Prerequisite condition

As a prerequisite condition of this test, the test will be developed without an additional new crash test due to serious budget limitations.

2) Study of evaluation for test method

"The report of Traffic Accident Case Study in 2007"[5] published by the Institute for Traffic Accident Research and Data Analysis (ITARDA) provided an accident analysis of rear seat occupants belted in by a 3-point seat belt in Japan. The report showed that frontal collisions caused the highest number of fatal or serious injuries for both car-to-car accidents (see Fig. 4) and single vehicle accidents (see Fig. 5). Therefore, the JNCAP has decided to adopt a frontal collision test to evaluate rear seat occupant protection as a first step.

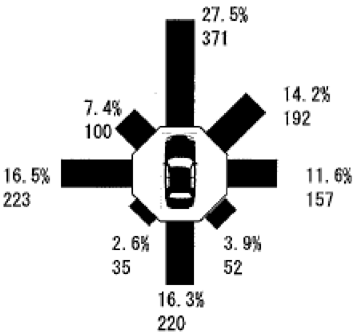

Figure 4. Car-to-car fatal or serious injury number of rear passengers with 3-point belt (N=1,180)

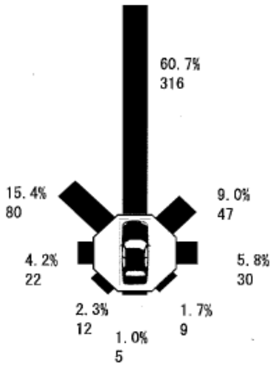

Figure 5. The number of rear passengers with 3-point belt having fatal or serious injury in single vehicle accidents (N=521)

The JNCAP conducted both a Full-wrap frontal collision test and an Offset frontal collision test. The Full-wrap frontal collision test[6] is reportedly appropriate for the evaluation of an occupant protection system such as a seat belt because of the high vehicle acceleration. The driver dummy and front passenger dummy data are used for the overall evaluation, and if another dummy was placed in the rear seat, it would be 3 dummies in the test vehicle. In this case,

a) It is rather difficult to install 3 dummies and measuring devices aboard a mini-car.

b) If 3 dummies are equipped, a rear dummy may contact a front dummy, thereby adversely affecting dummy measurements.

c) Generally speaking, there is some tendency for floor acceleration in a Full-wrap frontal collision to be more severe than for an Offset frontal collision. However, the North American traffic accident (NASS-CDS1997-2006) analysis conducted by the Japanese Automobile Manufacturer Association (see Fig. 6) shows that the injury risk to rear seat occupants in a Full-wrap frontal collision and an Offset frontal collision is nearly the same.

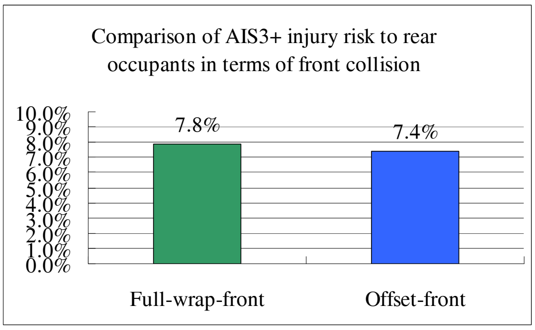

Figure 6. Comparison of AIS3+ injury risk to rear occupants in terms of front collision

The Offset frontal collision test, on the other hand, is suited to evaluate aggressiveness to the driver due to vehicle body deformation[6]. That is why the JNCAP utilizes only the driver-side dummy data for an overall collision safety performance evaluation.

d) Since the front passenger dummy measurement results are not used for the overall collision safety performance evaluation[6], and even if the front passenger dummy is moved to a rear seat, there is no influence on the overall collision safety performance evaluation.

e) In this case, 2 dummies are used, and measuring instruments are nearly the same, so it is easy to install these devices.

f) Additionally, the rear dummy does not contact the front passenger-side dummy because there is no dummy in the front passenger seat.

For all these reasons, the JNCAP decided to use the offset frontal collision test for rear occupant protection performance evaluation (see Fig. 7).

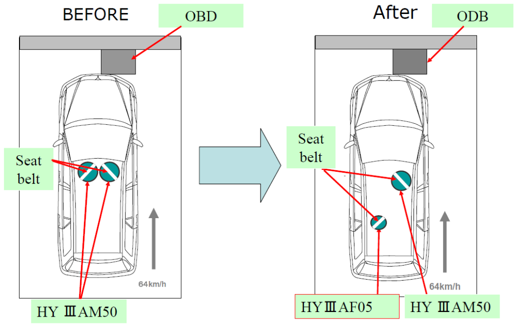

Figure 7. Dummy seating condition

We intend to popularize safety devices such as the seat belt pre-tensioner and force-limiter, and increase safety performance for the introduction of the rear seat occupant protection performance evaluation. Based on the traffic accident data in Japan[5], it is shown that women have a high rate of occupancy in rear seats, so we decided to use the Hybrid III AF05 Dummy.

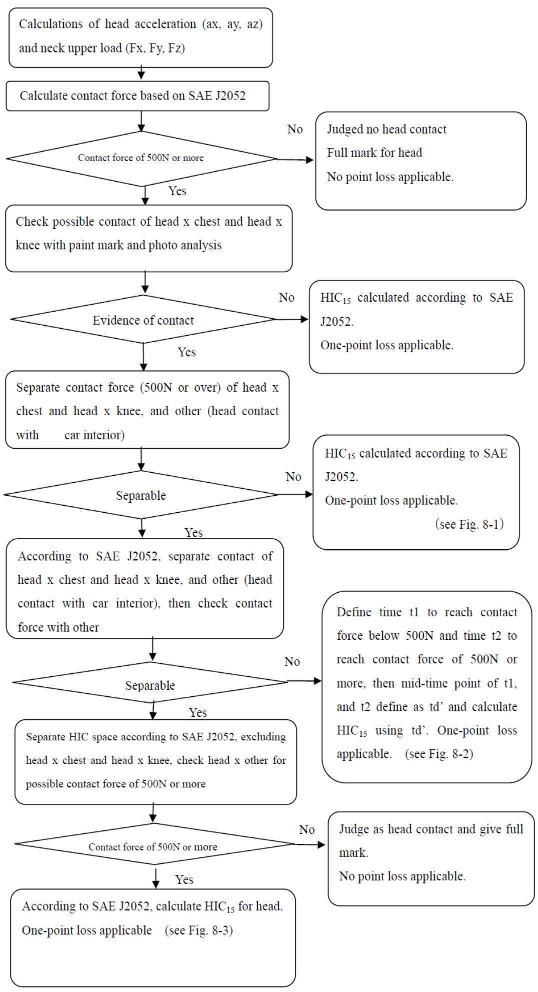

Figure 8. Proposed point calculation procedures for rear seat dummy head

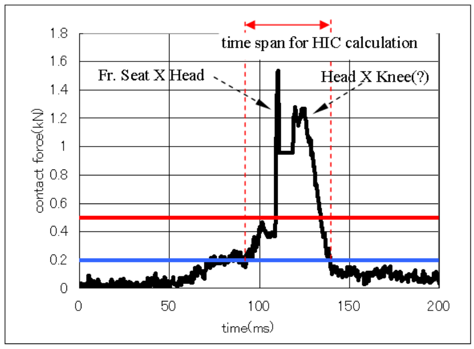

Figure 8-1. Example: Contact force not separable

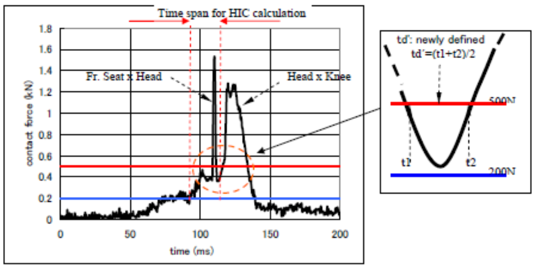

Figure 8-2. Contact force separable, but time not separable for HIC calculation

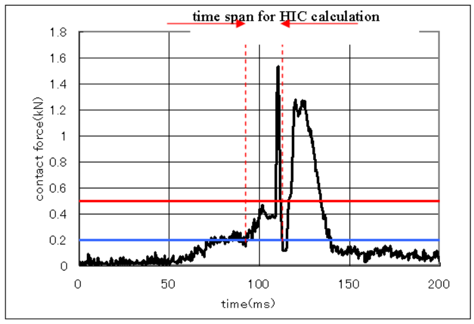

Figure 8-3. Both contact force and time span separable for HIC calculation

Referring to FMVSS 208[7] and US new NCAP[8], the injury evaluation criteria for rear seat occupants were established. Dummy parts for evaluation include the head, neck, chest, abdomen and lower limbs. Under secondary impact, we evaluate the head in HIC_{15} and also apply a -1 penalty point (see Figure 8.). When the external force acting on the head exceeds 500N according to SAE J2052, a secondary impact is considered to exist. In addition, we decide to exclude the secondary impact from a calculation of HIC, when a secondary impact occurred, since the secondary impact between the head and the vehicle interior is clearly separate as seen by the on-board camera. Here, we present an example of head contact with another body region. Figure 8-1 gives an example when dummy head contact with the vehicle interior and the head contact with another body region cannot be separated. (In these cases, all contact forces are used in the calculation to be on the safe side.) Fig. 8-2 shows an example in which the dummy head contact with dummy knee, etc. can be separated, but the HIC calculated time cannot be separated. (Head injury measurements are calculated by separating the HIC calculation time to remove the influence of head contact with the knee, etc.) Fig. 8-3 shows an example in which the impact wave produced when a dummy head makes contact with a dummy knee, etc. can be separated. (In this case, HIC is calculated to exclude head contact with knee, etc.)

HIC_{15} is calculated using the above-mentioned methods, and the HIC value is evaluated between 500 (lowest) to 700 (highest) like FMVSS 208[7].

Although JNCAP examined scaling of the cumulative time of upper neck tensile load, shearing load and flectional moment using in the previous AM50 evaluation to the AF05, some industry experts voiced their concern that many car models scored 0 points for neck, although actual accidents indicated a low rate of neck injury when wearing a seat belt compared with injuries of other body regions. Taking this point into consideration, we re-studied the neck evaluation method. The FMVSS injury index is derived from the reproduction of an actual accident using a Hybrid dummy in a 48 km/h Full-wrap frontal collision. However, this index was considered unsuitable for the ODB test, due to the long duration and inadequate verification. For this reason, we used SAE J2052 and decided to evaluate the peak value of tensile load between 1700 to 2620N, without a secondary collision. If the head had a secondary collision, the neck injury would be evaluated by the peak values of flectional moment of 36/49N, neck shearing load of 1200/1950N and neck tensile peak load.

Regarding chest injury, we referred to Laitiuri's paper[9], which also referred to the US new NCAP, and considered that Japanese average age was higher than that of the US. In addition, we considered the target age for the evaluation on side impact chest deflection in ISO/TC22/SC12/WG6. We decided to evaluate a chest deflection of 23/48 mm based on the risk curve of 40-years-old in the AF05 (see equations (1), (2), and Fig. 9).

$$P\Big|^{Thorax}_{AIS3+} = \frac{1}{1+e^{-\left(-12.597+0.05861Age+1.568\delta_{HIII50}^{0.4612}\right)}}, \quad (1)$$

$$\text{HIII05:} \quad \frac{\delta_{HIII05}}{0.817} = \delta_{HIII50}, \quad (2)$$

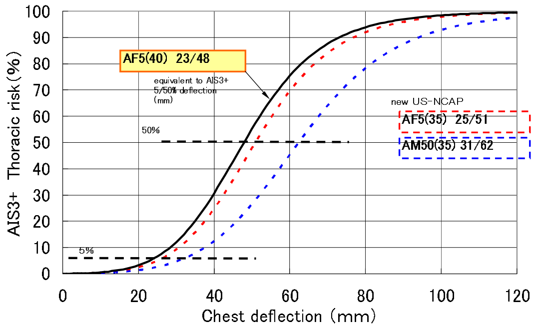

Figure 9. Risk curve of chest deflection for 40-year-old AF05

We intend to perform quantitative evaluation of abdominal injury in the future, but at this time we have tentatively decided to evaluate the pelvis restraint condition (evaluated by ilium restraint condition). (The pelvis is well restrained by the lap belt: 4 points; one side of the pelvis is not restrained by the lap belt: 2 points; both sides of the pelvis are not restrained by the lap belt: 0 points) This restraining condition will be judged using photography via an onboard camera and ilium load on both sides of the dummy.

We decided to evaluate the femoral load (4.8/6.8kN), which is already established verification method of the AF05. As weighting factors for these regions of the body, it was decided to use Japanese accident data involving fatal or serious injuries divided by the body regions for belted rear seat passengers, and average loss divided by injury levels. Based on these data, we calculated the human loss for every body region and weighting factor. The evaluation used these weighting factors (head: 4; neck: 1, chest: 4; abdomen: 4; femur: 2). For the dummy installation method, we referred to FMVSS208[7] and UMTRI developed AF05 installation method used by IIHS[12] and finalized the installation protocol.

Figure 10. Dummy seating arrangement for rear seat

(2) Usability evaluation for rear seat belt: planned introduction from 2009 FY

The JNCAP aims to increase the usability level of the rear seat belt because users have commented that the rear seat belt is not as easy to use as the front seat belt. Issues pertaining to rear seat belts are as follows;

a) Rear seat belt buckle is not readily buckled (it is difficult to insert the tang of the belt into the buckle one-handed).

b) Belt buckles for the outer seat and middle seat are not easily identified (the outboard/center passenger may not insert his/her tang into the buckle for center/outboard seat).

c) Tang accessibility may poor.

d) Rear seat arrangements vary widely, and the tang and buckle are sometimes hidden in or behind the seat.

To evaluate usability, we are planning to announce evaluation points based on an established objective evaluation procedure.

a) Easy insertion of buckle: Can the tang be inserted into buckle and latched easily with one hand?

b) Easy identification of buckle: Can the outboard and center seat belt buckles be easily identified by direction and/or layout?

c) Accessibility of seat belt: Use a 3D mannequin and measuring device to measure from the base point to the belt (evaluate at the standard seating position and most forward seating position)

d) Other: Evaluate tightening of the seat belt.

Additionally, JNCAP will announce installation of the 3-point belt for the rear center seat in our publication in advance of the regulation effective date, because the 3-point seat belt installation requirement for the rear center seat is not mandatory until 2012 FY.

(3) Evaluation of seat belt reminder (SBR) for passengers

The PSBR installation will be announced in the 2009 FY and quantitative evaluation will start in the 2010 FY.

Installation of the seat belt reminder for the driver seat is mandated, but SBR for seats other than driver seat is not. SBR for the front passenger seat is offered as an option in some car models, but very few offer rear seat SBR. Motoki[4], Lie[10] and others have reported on the effectiveness of a seat belt reminder in increasing the seat belt wearing rate. We believe the introduction of this evaluation for all passenger seats will aid in the popularization of SBR and increase the rear seat belt wearing rate. As part of the evaluation method of SBR requirements for passengers, we plan to examine methods for quantitative evaluation of the visible warning location and mode of warning, such as audible (signal, voice, etc.) and/or visual means this year. Before introduction of SBR quantitative evaluation to JNCAP, we plan to make a public announcement regarding whether or not the SBR is installed if it meets certain requirements, which referred to Japanese safety regulations or the requirements of the Euro NCAP[11].

3. Conclusions

The JNCAP has decided to introduce occupant protection methods for rear passengers to decrease the number of fatal or serious injuries to rear passengers in traffic accidents. As an evaluation method, we modified the offset frontal crash test and install a Hybrid III AF05 (female dummy) in rear seat instead of the Hybrid III AM50 (male dummy) used for the front passenger seat. The JNCAP developed its own rear seat dummy evaluation method referring to the FMVSS208 and new US-NCAP. In addition, the JNCAP introduced a usability evaluation for the rear seat belt and an evaluation of a seat belt reminder for all passengers.

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Development of the Virtual Testing Benchmarks (VTB)

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ABSTRACT

The SubProject 7 "Virtual Testing" [1] of the 7th FP Project APROSYS (Advanced PROtection SYStems) was aimed at development of a complete and consistent methodology for the implementation of the virtual testing of vehicles for safety improvement. Recall that by Virtual Testing we imply any analytical certification procedure which uses experimental and numerical simulation methods [2]. To achieve this goal, specific models, methods, and tools were developed. One of the final achievements relates to the future use of virtual testing in regulations, not only in the design of vehicles for safety [3].

The implementation of virtual testing in regulations would be a very complex process involving several steps [2], and concerning many different actors and stakeholders from car manufacturers to consumer organizations, and from regulatory bodies to experts group in automotive engineering. Among the many envisaged steps, which are being currently structured in a specific roadmap, there is the qualification problem. For both type of accreditation method, either the type approval scheme usual in the EU, or the US style self-certification scheme, a qualification process is required.

To this aim the authors propose to establish a series of benchmarks, the Virtual Testing Benchmarks (VTB), to be used for qualification at two different levels: codes and methods validation, and operators' qualification. These benchmarks consist of typical crash cases to be tested in the virtual environment: there are several different cases covering different topics of modeling (different element types, material models, contacts…). The code validation can be achieved by giving a well defined problem to be solved, whereas the operators qualification can be achieved giving a less defined framework and leaving more freedom to the operators to generate their own models of the problem.

At least 5 different cases are provided and described in the paper. Verification by means of experimental or theoretical solutions is given. Of course, this will not cover all possible modeling situations but is a first step towards this electronic certification.

1. INTRODUCTION

One of the main concerns about the applicability of VT in regulations is the validation of the VT predictions. In the APROSYS SP7 workshop, held in 2007 at the Delft TNO location, a presentation [4] was given putting in evidence possible downsides for the applicability: different codes were shown to give different results. A discussion was initiated during the period following that workshop, coming to a couple of main results [5]:

1. **VT is** the results of the application of **a model**: whatever the model and whatever sophisticated, detailed, and accurate the model **it will always have limits of validity** and, therefore, does not extend to any possible boundary conditions and scenarios unless with careful verification
2. It is necessary to have some validation procedures for VT

VT is a complex methodology, which has many of aspects, all examined in this APROSYS subproject:

- Virtual models
- Virtual methods
- Virtual tools
- Virtual testing procedures

As a consequence, it involves several "components" and steps within the preparation and development of a VT approach:

- The model data (materials data, dimensional data and geometry, contacts...) and the scatter involved in the set of data (dispersion, distribution...)

- The code (with its implemented material models, element models, and their options, contact models and definition, boundary conditions...)
- The computer used in the analysis, including the interface with the codes and with the operator
- The procedures and scalars used for the analysis and evaluation stated either internally in the company or the research centre, or externally by some institutional reference (national or international standard, EU directive or any applicable national or international law, other institution or organization like NAFEMS, APROSYS standards, etc.)
- The operator himself, with his skills and experiences, including the possibility of human errors during the manual work

Thus, several validation levels should be taken into account and different benchmarking procedures should be defined. Already within the ADVANCE FP5 project, a multi-level validation approach for crash models was proposed [6]. The validation of a model was, in this case, at the component, subsystem, and full-vehicle or car compartment levels.

Consequently, within APROSYS benchmarks for Virtual Testing have been conceived. They are called Virtual Testing Benchmarks (VTB) and try to solve the previously discussed problems by treating most of the proposed items. In the current definition of the proposed simple models to be used as a basis for a benchmark procedure, two validation phases have been selected:

1. Human factor influence or operator validation
2. Instrumental certification or code validation (including the validation of the models implemented in the codes, the data input/output and the computer used in the analysis)

In phase 1 only generic definition are given since it is exactly the human factor that has to be assessed. That is, the test case is only defined in general terms, and although fully detailed, no mesh or input cards are given. It is the operator's job to prepare his/her own model, selecting the types of elements and material models that he/she thinks most appropriate for the purpose, etc.

In phase 2 all that can be associated to the human factor has to be avoided or at least limited as much as possible. This is done not only by precisely defining the test case with all its input data and parameters, but also by giving the involved operator the explicit inputs in terms of geometry (that is, even the mesh is given in some widely used format or some general purpose definition style), materials data (in terms of input values or curves in some reference format universally accepted or precisely documented), contact definitions, etc.

Reference results are given for the validations. The reference results are obtained either from experiments, from a theoretical model, or from validated simulations whenever neither experiments nor a sound theory are available.

In the following section, the various proposed cases are summarized. The cases are then described and commented in details. All the data that are not suitable to be written on a document will be available on files.

It was the aim of the authors in this activity to cover the main topics of interest for crash simulation. In this respect, the different cases consider different types of elements (solids rather than shell elements), different materials (polymeric foams rather than metals), and other essential modeling issues like, for example, contact definition (including modeling of friction, elastic constant...).

The family of simple cases or benchmarks for VT finalized up to now is considered a starting point. Since the development in APROSYS DIP3 and DIP4 were focused on pedestrian protection (mainly head and leg impacts), the partners chose to select a set of cases related primarily to this subject. The B-pillar case, and future proposals, will cover all the other aspects related to safety and crash simulations.

The VTB method should be, in the authors' idea, a common background for engineers approaching virtual testing, but also for all the people working in crash simulations. The VTB family should continuously improve and adapt to the ever changing requirements of simulations and evolution of modeling codes and techniques.

2. VTB OVERVIEW

Table 1 and Figure 1 summarize the main aspects taken into account with the VTBs. Each case is described synthetically here and will be addressed in details in the following section.

In phase 1 the modeling capacities have to be evaluated, and, therefore, most of the job is left to the operator under review. No mesh or material cards can be given, but a precise geometrical description together with material curves and indications of the type of material model to be used (i.e. elastic vs. plastic, hardening model, strain-rate sensitivity…). The choice of the type of elements is somewhat enforced, but freedom is still given for what concerns the element formulation (fully integrated vs. under-integrated, linear vs. parabolic…). Perhaps the most difficult problems, as is often with FE analyses, arise from boundary conditions modeling: contact is for example a critical issue to be addressed.

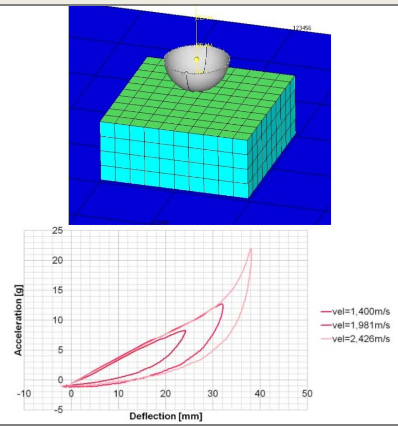
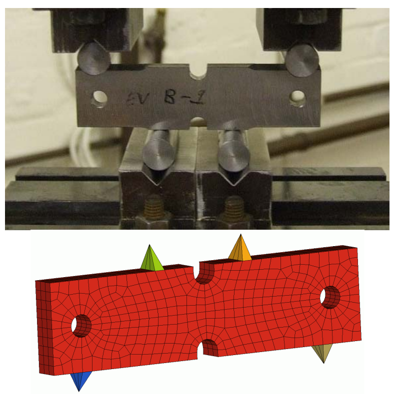
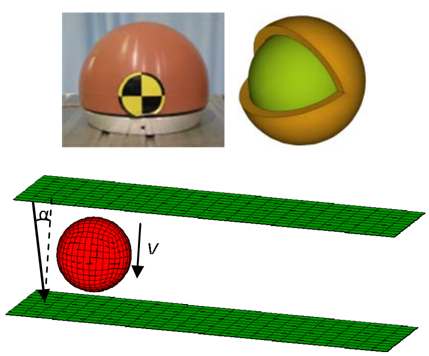
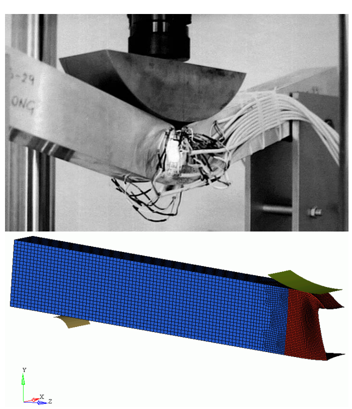
Table 1.
Summary of the VTB cases

Name	VTB1	VTB2	VTB3	VTB4	VTB5
	Foam	Legform	Bouncing	Bending	B-pillar
Description	Impact on foam	Legform knee	Bouncing ball	Bending beam	B-pillar impact
Scope	Evaluate modeling of soft foam materials for dummies and other EA components	Evaluate modeling of metals and of bending situations, solid elements	Evaluate modeling of contacts, energy management and stability	Evaluate performance of shell elements, simple contacts	Same as for VTB4
Material	Foam+rigid impactor	Elasto-plastic	Elastic	Elasto-plastic	Elasto-plastic
Elements	Solids (shell only rigid)	Solids (shell only rigid)	Solids	Shells	Shells
Other			Contacts		
Phase 1	Foam material stress-strain curves at different strain-rates (loading/unloading)	Geometry and description of the case. Material description	Geometry and description of the case. Main material properties (elastic)	Geometry and description of the case. Main material properties (elasto-plastic). Contact parameters.	Same as for VTB4
Phase 2	Mesh Foam material model specification and curves	Mesh Boundary conditions Material data (yield stress, yield curve, strain rate sensitivity)	Mesh Material (elastic) Contact definition Contact parameters	Mesh Boundary conditions Yield stress curves	Mesh Boundary conditions Yield stress curves
Validation	Experimental curves	Experimental curves	Theoretical results (for the 0° case only)	Experimental results	Simulations results

In phase 2 topics like material and element modeling are crucial. This activity is aimed to evaluate code functionality and ability to correctly address these features; therefore it is necessary to fix the other modeling issue: the geometrical description is given (mesh and boundary conditions) together with a detailed description of the material model and of the necessary curves.

The last issue in the definition of the VTB regards the evaluation of the results.

Comparison results have to be provided. Two approaches are possible: the comparison can be with experimental results or with some theoretical prediction. The first possibility is preferable, for obvious reasons. However, whereas most of the VTB come from real cases and have a physical counterpart, in some cases the problem is only “virtual”, that is, is a generic problem with, possibly, a theoretical solution.

Name	Description
VTB1 Foam	
VTB2 Legform knee	
VTB3 Bouncing ball	
VTB4 Bending beam	

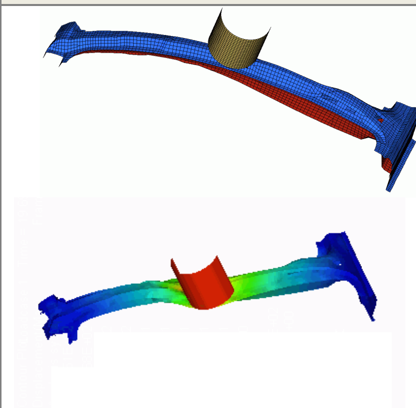
Name	Description (cont.)
VTB5 B-pillar	

Figure 1. Pictorial summary of the VTB cases

3. VTB DETAILED DESCRIPTION

Following is a description of the first five VTB defined. As discussed previously, the VTB family would be further increased and improved with more cases related to impact and crash analysis.
These five cases are as follows:

- VTB1: Foam
- VTB2: Legform
- VTB3: Bouncing
- VTB4: Bending
- VTB5: B-pillar

The impact of a ball on a piece of foam (VTB1) and the impact of a headform like spherical component between two rigid surfaces (VTB3) are inspired to the activities carried out in APROSYS SP7 (head protection demonstrator [3]). The knee ligament test (VTB2) is equally motivated by APROSYS SP7 (leg protection demonstrator [3]). The last two cases (VTB4 and VTB5) come from typical crash situations.
The various VTBs try to cover as many modeling topics as possible. As previously argued, future needs can be equally covered by defining more VTB cases.

3.1 VTB1: impact on foam

The first VTB can be summarized as follows:

- Description: hemispherical impactor on foam specimen
- Aim: evaluate modeling capacity for solids and soft materials
- Reference: experimental impact tests on an EPP foam

Highly compressible low density foam models are often used in passive safety numerical simulation. Main applications are for seat cushions and padding elements on biomechanics test devices. A compression test with a spherical impactor on an EPP 20 g/dm³ foam specimen is proposed as VTB test (Figure 2).

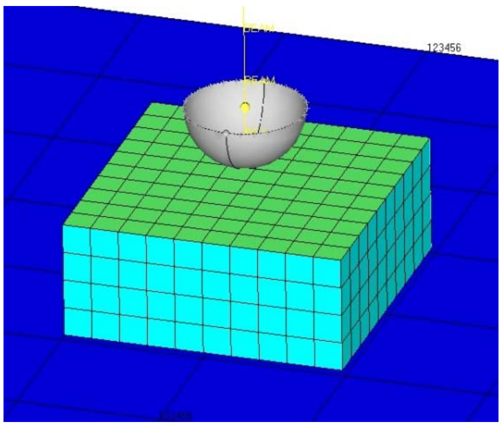


Figure 2. Impact of a spherical impactor on low density foam model

In phase 1 of the evaluation of this VTB only generic guidelines about geometry, boundary conditions and material have been given to the different operators that worked on the model. In particular:

- The foam specimen is 42 mm thick with a base of 110 mm × 110 mm
- The rigid spherical impactor has a 42.5 mm diameter, an 8.3 kg mass and different test velocities: 1.4 m/s, 2.0 m/s and 2.4 m/s.
- Some graphs (Figure 3) based on foam material experiments

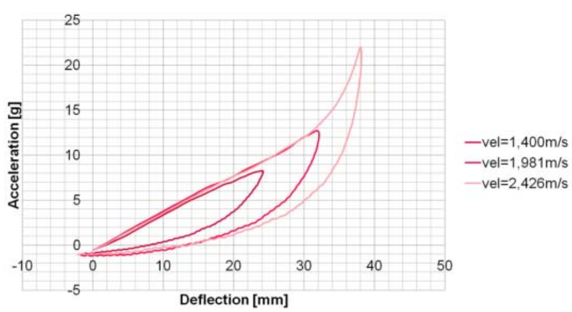


Figure 3. Impact of a spherical impactor on low density foam model

In phase 1 the model has been developed for three different codes (RADIOSS, LS-DYNA, and MADYMO).

In phase 2 the same mesh for the foam has been used for the different models and the foam material model has been chosen as similar as possible between the different codes in order to give to the imaginary operators not only the experimental foam results but directly the material defined for the used code.
In this case also, the model has been developed in RADIOSS, LS-DYNA and PAM-CRASH.
All the different data specified for phase two are summarized in Table 2.

Table 2.
Data specified for phase 2

Average element dimension	10 mm (10×10×4 elements)
Boundary conditions	Supported (not constrained) on a rigid plane
Data for material card	Depends on code
Young Modulus	1.89 MPa
Density	20 g/dm³
Poisson Ratio	0.02 (for compression)
Compression Curves	at 0, 1×10^{-6}, 1×10^{-4}, 2×10^{-1} and 1×10^{-1} strain-rate
Tension Curve	
Unloading Curve	

Numerical results have been compared between codes, but in this case with experimental results also.
A qualitative comparison of results is represented in Figure 4. The three codes analyzed are able to reproduce the experimental test at different velocities with sufficient fit of the experimental curves. Figure 5 reports some results of an unacceptable case of analyses performed. The scatter is not acceptable and more detailed modeling is required.

3.2 VTB2: legform knee

This second VTB can be summarized as:

- Description: knee joint element used in the EEVC WG17 (WG10) legform to bumper test
- Aim: evaluate modeling of steel materials
- Reference: experimental 4-point bending tests

The deformable, simulated knee joint element (Figure 6) used in the EEVC WG17 (WG10) legform to bumper test has been chosen for the second VTB [7-8].
The geometry has been obtained from the sketch shown in Figure 6.

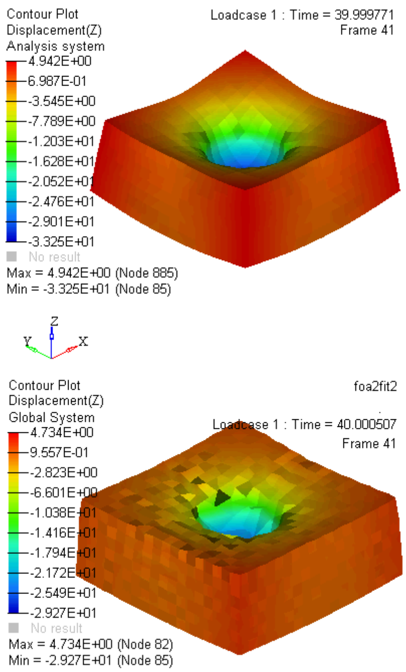


Figure 4. Comparison of the results obtained from two of the used codes

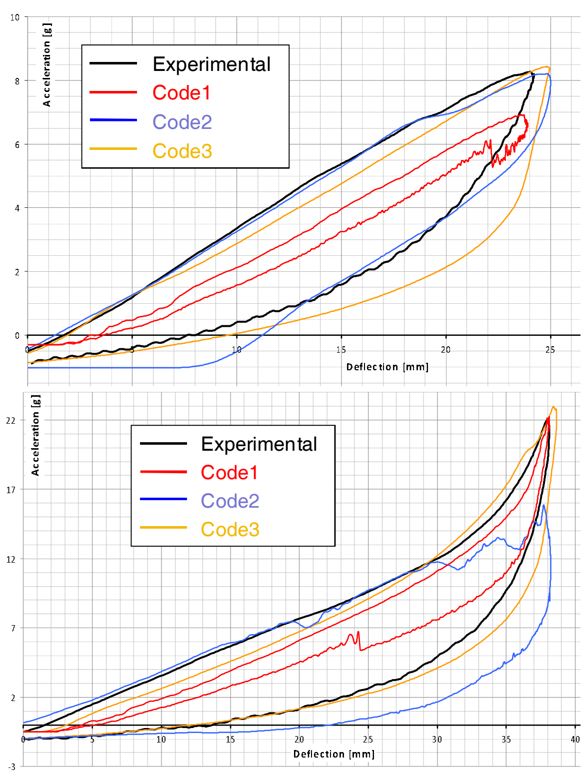


Figure 5. Comparison of some unacceptable results

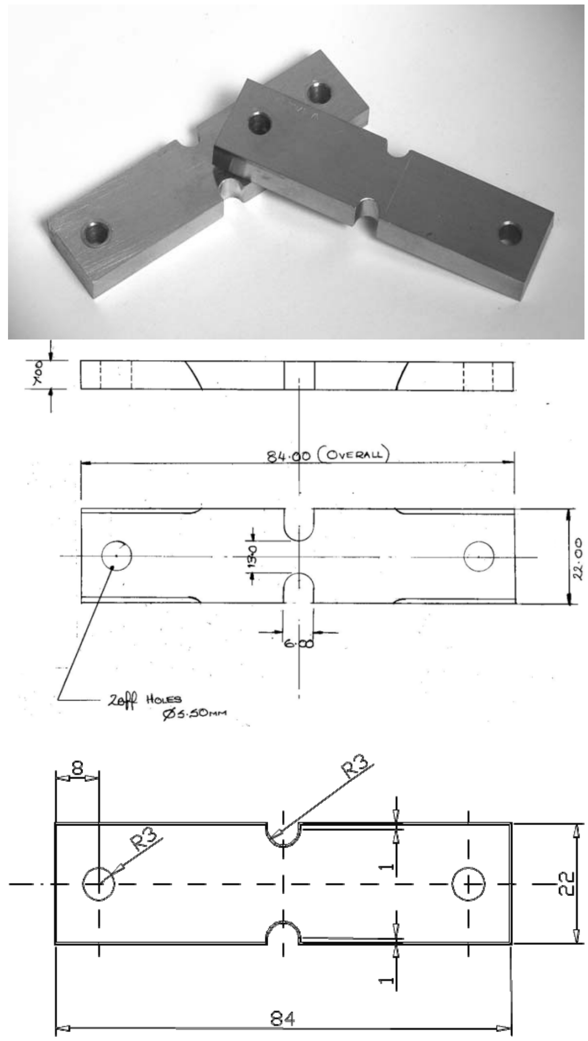


Figure 6. The EEVC knee ligament: photo of the component, sketch, and detailed drawing

The aim here was to obtain an easily reproducible test, avoiding the experimental and numerical complexities and uncertainties of a "real" case. Therefore, the ligament only was tested, and not the entire legform. Testing the ligament in bending can be made at least in two configurations (Figure 7). The first is the usual 4 point bending test. A second case is the 4 point asymmetrical loading, shown in the same Figure 7. In this case the middle section is loaded in pure shear instead of pure bending. This loading case has not been considered yet, but it is certainly a future possible step ahead in VTB method development.

The knee specimen has been modeled by using a mild steel material (Table 3).

The behavior in terms of moment vs. rotation and force vs. displacement histories has been used as reference for the comparison between the different codes. In particular, in order to compare numerical results with experiments also, boundary conditions schemes represented in Figure 7 have been considered and the force vs. displacement history of the impactor has been used. The experimental results are reported in Figure 8.

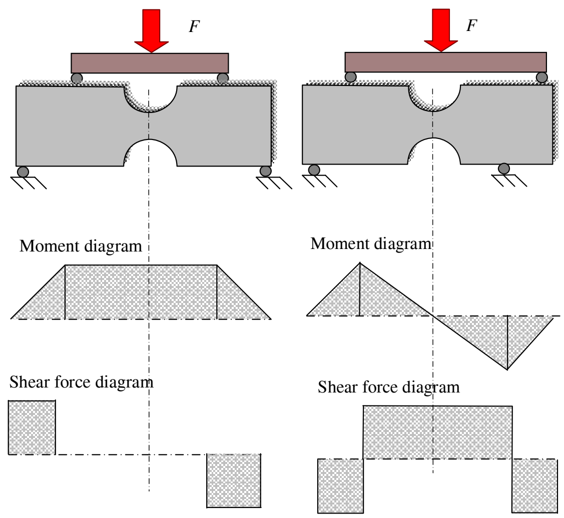


Figure 7. Loading schemes for the knee ligament: left, classical 4 points bending test; right, 4 points asymmetrical loading

Table 3.
Material data VTB2

Material model	Bilinear
Density	7.8×10^{-6} kg/mm3
Young modulus	210 GPa
Poisson ratio	0.3
Tangent modulus	6 GPa
Yield stress	150 MPa
Element property	Reduced integration
Impactor velocity	0.06 m/s
Support material	Rigid

The VTB results, given here for phase 2 only, are in good accordance with the experimental results. The comparison with the experimental results is shown in Figure 9, whereas Figure 10 shows a simple comparison of the deformed shapes obtained from two of the codes already mentioned (LS-DYNA and RADIOSS). It is important to notice, the level of details necessary despite the simplicity of the problem. Some preliminary investigations demonstrated that simpler boundary conditions' modeling is insufficient to obtain the correct behavior.

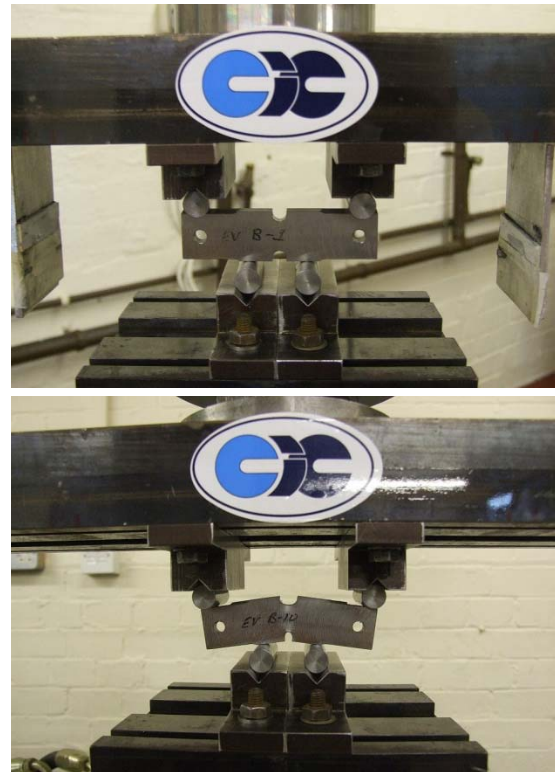


Figure 8. Experimental results for comparison

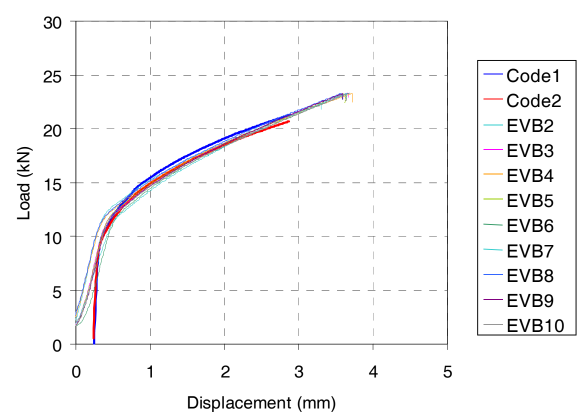


Figure 9. Comparison of the experimental curves with the numerical simulations of two codes used

3.3 VTB3: bouncing ball

This third VTB also inspired by the headform experiment for pedestrian protection has the following characteristics:

- Description: a spherical head, similar to the adult headform of the pedestrian, bouncing between two rigid parallel surfaces
- Aim: evaluate modeling for contacts
- Reference: analytical/numerical solution

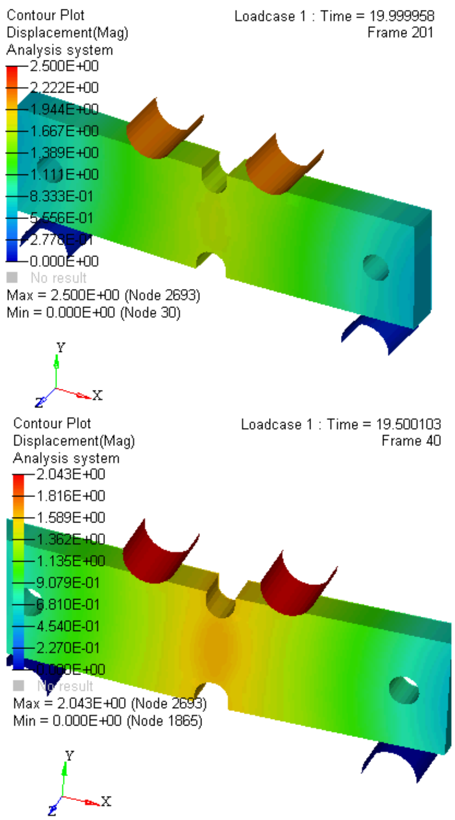


Figure 10. Comparison of the numerical results from two explicit simulation codes

The case is explained by Figure 11: a ball made of aluminum covered by rubber, is constrained to bounce between two rigid surfaces moving at an initial given speed v_0 and angle α.

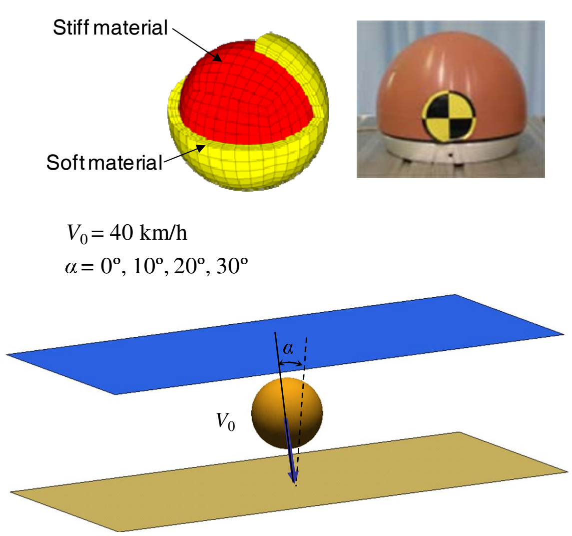


Figure 11. The VTB3 case

In VTB3 focus is on the modeling of contacts rather than on materials that are simplified as linear elastic. This is to avoid that possible difficulties in material modeling overshadow the contact modeling aspects.
The sphere is launched normally against the first wall with a v_0 velocity equal to 40 km/h (as in Figure 11). The angle α between v_0 direction and the surface normal varies (0°, 10°, 20° and 30°) to take into account contact friction. Tables 4 and 5 give additional details about the problem.

Table 4.
Definitions for VTB3: phase 1

	Elastic modulus (GPa)	Density (kg/mm^3)	Poisson coefficient
Inner sphere, 80 mm radius	70	2.8×10^{-6}	0.3
External layer, 12 mm thick	0.05	1.05×10^{-6}	0.3

Table 5.
Definitions for VTB3: phase 2

Fixed planes	Meshed with elements (not defined as rigid planes); E = 210 GPa (for contact stiffness)
Contact properties	Surface to surface contact
Solid element	Full integration
Solid elements covered with skin of null shells or segments	
Static friction coefficient	0.6
Dynamic friction coefficient	0.6
Contact thickness (gap) for both slave and master side	0.5 mm

Contact force histories and sphere trajectories have been considered for the comparison between the different models.
For this VTB also, the work has been divided in the two phases. In addition to the general description given to the operators during the first phase, mesh density and contact definition and parameters have also been given in the second phase. The different requirements for phase one and two are summarized in Tables 4 and 5.
Figure 12 shows a comparison of some results obtained at different moving angles. Together two images of two different models, obtained from different operators as in phase 1, are reported. Figure 13 reports two comparisons in terms of contact forces vs. time: first the phase 1 comparison is reported, and the phase 2 results follows.

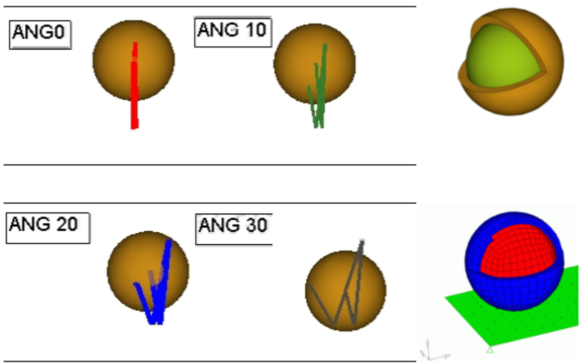


Figure 12. Some VTB3 results at different angles: lines overlaid to the balls images represent the trajectories. On the left different models obtained from a couple of different operators in phase 1 analysis

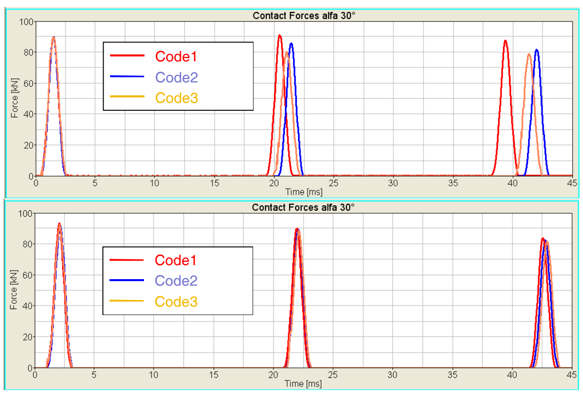


Figure 13. Results from phase 1 and phase 2 analyses: contact forces vs. time; angle 30°

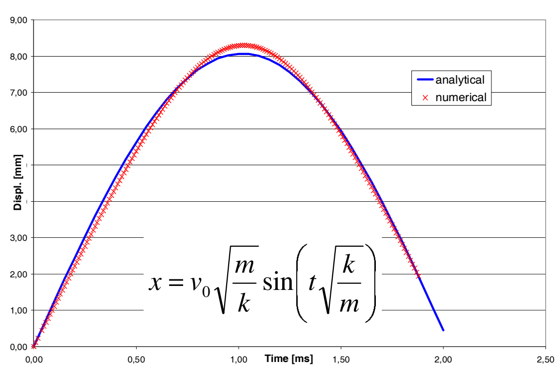


Figure 14. Theoretical approximation of the ball impact

As expected, there is a certain amount of scatter between the results from phase 1: the uncertainty on the data is slightly greater. However, phase 2 comparison is excellent and the three used codes already mentioned give more or less the same results. Some minor discrepancy appears after repeated impacts.

Finally an approximate theoretical solution is available and shown in Figure 14.

3.4 VTB4: thin walled beam bending

The VTB4 problem is summarized as follows:

- Description: formation of plastic hinges in a thin-walled square cross section aluminum beam
- Aim: evaluate shell modeling capability
- Reference: experimental bending tests [9]

Deep bending collapse is often the main failure mode in the thin walled tubular members of vehicle structures. This occurs because this energy absorption mechanism requires a lower specific energy (dissipated energy/material volume) than the axial crushing. This VTB is related to the formation of plastic hinges in a thin-walled square cross-section aluminum beam. The numerical model tries to reproduce the experimental test represented in Figure 15.

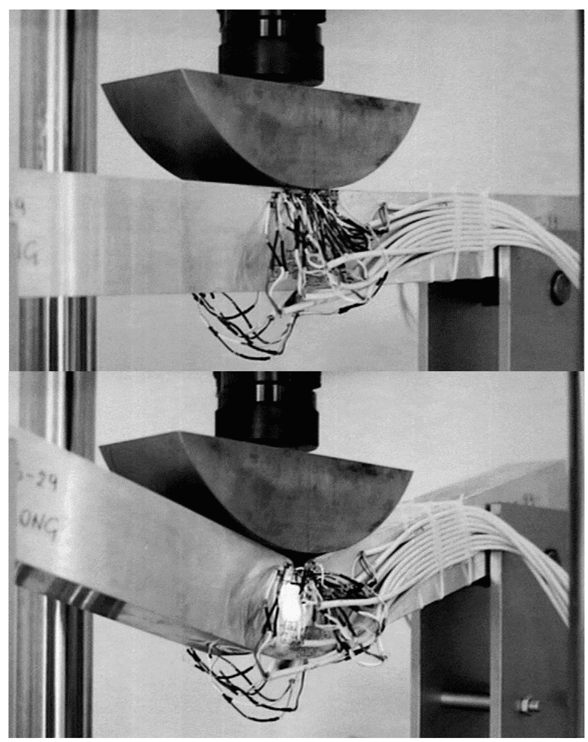


Figure 15. The VTB4 experiment [9]

For this case, only phase 2 has been considered. The model has been developed in LS-DYNA, RADIOSS and MADYMO and the mesh in Figure 16 (taking into account double symmetry of the problem, only one quarter has been modeled). The main problem data are summarized in Table 6.

Table 6.
Definitions for VTB4

Property	**Value**
Shell thickness	2 mm
Material properties	Piecewise Linear Plasticity
Density	2.7×10^{-6} kg/mm^3
Young modulus	70 GPa
Poisson ratio	0.3
Yield stress	0.079 GPa
Contact properties	Surface to surface contact
Static friction coefficient	0.61
Dynamic friction coefficient	0.47
Contact thickness (gap) for both slave and master side	2 mm
Impactor	Rigid
Support	Rigid

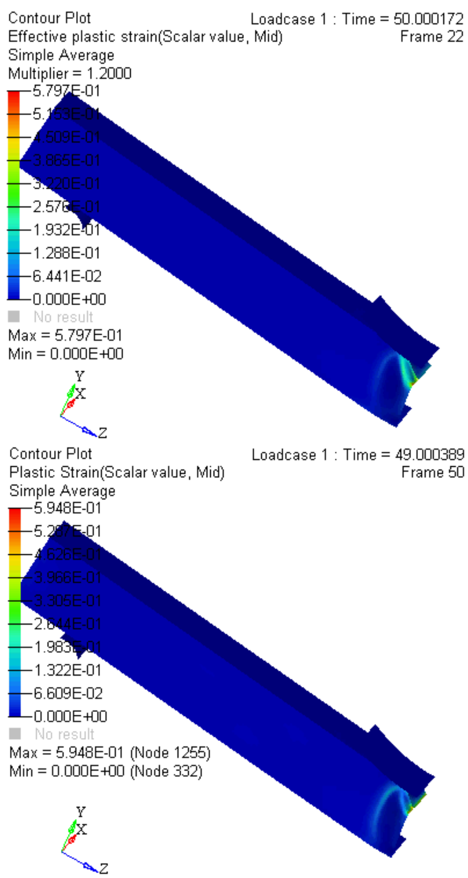


Figure 16. The VTB4 numerical result

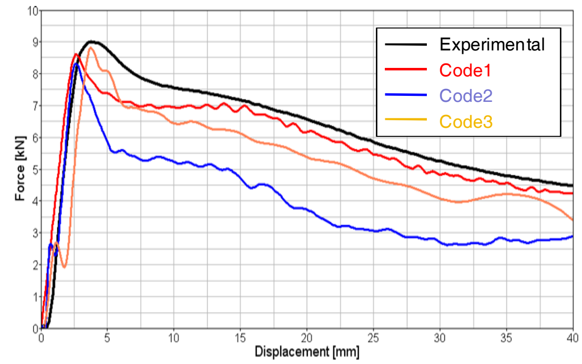


Figure 17. The VTB4 results comparison

The comparison is acceptable for all the three codes used (Figure 17). Of course, small differences cannot be avoided since different modeling (materials, elements, contacts…) are present. One of the codes gives more dissimilar results and is not really acceptable in this case.

3.5 VTB5: B-pillar impact

The VTB5 problem is summarized as follows:

- Description: bending collapse of GCM4 B-pillar
- Aim: the use of shell elements, contacts, inelastic materials
- Reference: Numerical simulations of the APROSYS GCM4 [10]

The GCM4 (Generic Car Model 4) is one of the results of the FP6 APROSYS project. Generic Car Models [10] are virtual vehicles developed to be shared between researchers without confidentiality restrictions. These models of vehicles (5 car of different sizes and a heavy truck model), provided for some typical impact scenarios, are validated against the best-in-class models on the market.
Even if this VTB seems quite simple if compared to real crash analyses, it is of interest taking into account different aspects of a complex crash analysis, and it can be useful to investigate differences between codes due to:

- the use of shell elements for sheet components
- contacts
- non elastic materials

The pillar is composed of two parts connected by means of rigid spot-welds and it is fully constrained in its extremity. A cylindrical impactor is moved with an imposed velocity of 8 m/s. The impactor is modeled as a rigid component.

An elasto-plastic material model, usually known as simplified Johnson Cook, has been used. The flow stress is given by:

$$\sigma_y = \left(A + B\varepsilon_p^N\right)\left(1 + C\ln\varepsilon^*\right)$$

Table 7.
Parameters for material model

Material Parameter (*)	Value
Density, ρ	7.8×10^{-6} kg/mm^3
Young modulus, E	200 GPa
Poisson ratio, ν	0.3
A	0.25 GPa
B	0.08 GPa
N	0.60
C	0.03

* Units in table are referred to a mm/ms/kg/kN set

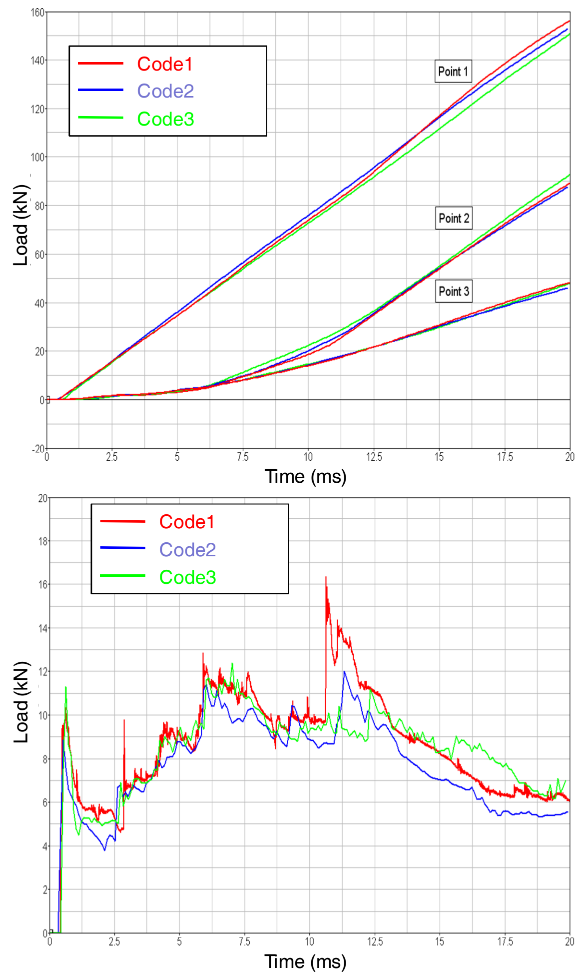


Figure 18. The VTB4 numerical result

Values for the parameters are summarized in Table 7.

Final deformed shapes, contact forces and node displacements have been taken as references.

In Figure 18 a comparison of the displacement of some reference points between the three examined codes is reported, together with a comparison of the global load exchanged with the supports.

The results (phase 2 analyses) are quite encouraging despite the difficulty related to the complexity of the problem (Figure 19).

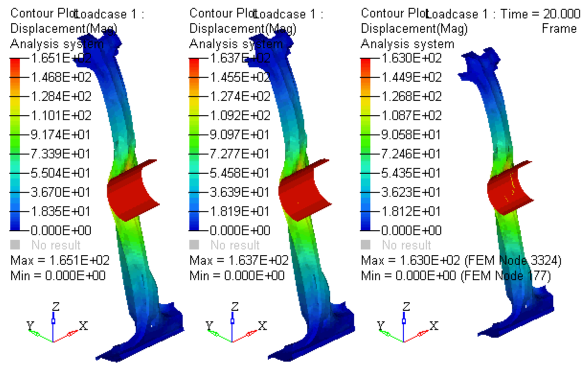


Figure 19. B-pillar results comparison between three different codes

4. DISCUSSION

The examples shown demonstrate the capability of different software codes to replicate real crash type scenarios accurately.

The accuracy of results obtained has shown to be improved if material data has been obtained prior to performing the analysis. The implications for full scale virtual testing mean that smaller component tests may be critical in building more accurate models. These smaller component tests may be a simple material test or a sub assembly of the structure which can be tested in isolation.

Although it is recognized that there are differences in the material models of different codes, in general, they demonstrate the capability to reproduce real life scenarios.

When performing a blind simulation the need to provide as much information as possible is essential. This has been demonstrated mainly in the knee impactor scenario. Material and boundary conditions must be accurately stated.

When a physical test was repeated for the knee impactor, a cloud of data was obtained. In a similar manner, there is also a scatter of results when using different software codes. For future VT legislation it is important to characterize the scatter from repeat tests and understand the implications when performing simulations.

5. CONCLUSIONS

A first step towards electronic certification of numerical codes for crash analysis and of the operators working on impact simulations has been made. This step is very important to fully exploit the potentiality of virtual testing and make it acceptable as a tool for certification.

To do this a series of simple case studies, called Virtual Testing benchmarks (VTB) has been defined.

The examples presented in this work are representative of situations mainly related to head and leg impact situations (EC regulations 2003/102/EC). Each different case tries to analyze an important aspect of the model and considers different topics arising in each situation (element type, material modeling, etc.). References are also given, from experimental, analytical, or numerical results. The simulations allow to certificate by comparison either the operators (phase 1) and the codes (phase 2). In most cases some codes were checked and fully validated. An important further step is the definition of metrics to evaluate and accept or reject the obtained results. It is also to be noted that we have not presented here the complete 3R method (rating, reliability and robustness) which was devised during the APROSYS-SP7 project which provide a full assessment methodology for a virtual testing scenario to be implemented (a paper is in preparations).

This is a first proposal to define VTBs, to be included in a full or partial virtual testing regulation investigation. More cases are being defined by the authors and the results which include the widest range of simulation capabilities will be published regularly, depending on the accident scenario investigated. Up to now VTBs can be used for internal self certification, but some quantitative assessment system is necessary to use virtual testing in regulations.

ACKNOWLEDGEMENTS

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CNG CARS SAFETY IN ACCIDENTS (CASE STUDY:IRAN)

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ABSTRACT

In the last decade,air pollution has become a major problem in metropolises.Therefor using alternatives for common fuels, especially gasoline was ordered. In a country like Iran with the second biggest natural gas resources in the world, CNG was the most important choice.This potential led to vast manufacture and usage of CNG consuming automobiles. Being used in different climates and areas and because of the susceptibility of natural gas,these automobiles have always been vulnerable in accidents.
Based on the statistics from reliable sources and scientific methodes,this research tries to present the order of importance of CNG fuel system parts in accidents.The results of this reaserch will reveal the priority of making the system parts safe.

INTRODUCTION

After the prevalent manufacture and usage of bi-fuel engine aoutomobiles ,especially CNG consuming automobiles in the recent years, currently there are around 750000 automobiles of such kind in Iran.This puts Iran in the forth place among the countries using alternative fuels. The parts of the fuel systems of CNG automobiles are manufactured under strict standards and are installed on the automobiles both in factories and workshops. The information received from reliable sources shows flaws in different parts during the usage and in accidents. The results shows problems first in unprotected areas and then in the the assemblage of parts.
These problems have mostly occured with the systems which have been installed in workshops and caused incidents like fire or explosion.
Using the statistics of the parts damaged in accidents happened to CNG automobiles and analyzing them using Delphi method,this research presents the scientific ranking of the importance of securing and checking the parts.The results could be used in the process of writing and correction of the standards,as well as the manufacturing and installation.

RESEARCH METHOD

In order to have results most compatible to reality,this article tends to apply the CNG and car safety expert's opinions as well as group decision making to give the best possible picture of CNG system weak points.
This research is based on Delphi method,hence a brief explanation of this method is presented.
In the early 1950s a project known as Delphi was satarted by th U.S air force.The goal was to use the the experts opinions to estimate the number of Russian atomic bombs that can cause a certain damage in the USA technic called Delphi was used in this project.This technic aims to access the most reliable group agreement (of the expert`s opinoins) for an issue and it does through questioning the experts frequently and questionaires. Dephi method has three properties,impartial answers to the questions,repeated sending of the questionaire, and collecting and analysing the answers in groups.
The number of resendings varies between 3 to 5, and depends on the answerer's agreement and the additional information needed. The first questionaire usually needs answers to a major question while the other questionaires are based on the the answers to previous ones. Delphi process stops when a group agreement has been reached or sufficient exchange of information has been done.
Delphi method has 11 levels which are the followings:
1.Preparation of the questionaire
2.Choosing the expert group
3.Propounding the main question in the first questionaire
4.Analysys of the answers collected from questionaire no1
5.Preparation of the second questionaire based on the answers from questionaire
6.Analysys of the answers collected from questionaire no 2
7.Preparation of the third questionaire
8.Analysis of the third questionaire
9.Analysys of the answers collected from questionaire no3
10.Preparation of the final report of the Delphi process
11.Informing the questioned experts of the results

CASE STUDY

First the experts who are going to answer the questions are identified.This group consists of experts in CNG installation and safety who work in automobile factories,traffic police and etc.
The minimum number of experts is 10 to 15 ,suggested by Delphi method,which can be more if possible.In this research almost 20 experts opinions have been used.
In the next stage,the key question is prepared and the first questionaire is presented.In the first questionaire,we tend to expose the experts to the general information and then the details are presented to clarify the possible ambiguities.
In this questionaire the experts are asked to choose the most important parts of the CNG fuel system.These parts are the followings:

1. tank
2. steel pipes
3. tank valve
4. feeding valve
5. solenoid
6. safty valve
7. electrical circut wires
8. stepper
9. regulator
10. electronic control unit(ECU)
11. connection nut
12. mixer

After the important parts are identified,a questionaire called questionaire no2 is prepared.
In this stage experts have been asked to use their experience to give each of the parts a factor of importance between 1 and 12.
No 12 shows the most important part while no 1 is the least important one.
After the responses were analysed,the geometric averages of weighted index assiegned by the experts have been calculated.
The resultant numbers have been written in the tables of another questionaire and given to the experts.
Being informed about the averages of the numbers assigned by the other experts,each expert is able to delibarate and present the best possible value for the final weighted index.
The final index of importance for each part gained from questionaire 3 are given in table 1.

Table 1.
CNG system`s part final weighted index

element	tank	Steel pipes	stepper	Connection nut	safty valve	tank valve	solenoid	regulator	ECU	electrical circut wires	feeding valve	mixer
Final weighted index	2.47	9.18	4.75	7.03	7.52	4.09	5.60	5.47	3.87	3.91	4.45	3.54

After the factors are written down,it's time to make the pair comparison matrix, in which:

$$a_{ij} = \frac{1}{a_{ji}} \forall i, j = 1,2,3,...,n \qquad (1)$$

If the judgments are totally compatible and stable, they should:

$$a_{ik}.a_{kj} = a_{ij} \forall i, j, k = 1,2,3,...,n \qquad (2)$$

Because:

$$a_{ik}.a_{kj} = \frac{w_i.w_k}{w_k.w_j} = \frac{w_i}{w_j} = a_{ij} \forall i, j, k = 1,2,3,...,n \qquad (3)$$

Hence the inputs of this matrix are correct only when we have full satability and a_{ij} could be gained from equation 4.

$$\left(a_{ij} = \frac{w_i}{w_j} \right) \qquad (4)$$

In figure 1 the pair comparison matrix for prats of CNG system is presented.

Figure 1. Pair comparison matrix in related to CNG system`s

$$\begin{bmatrix} 1.0000 & 0.2695 & 0.5205 & 0.3521 & 0.3290 & 0.6053 & 0.4417 & 0.4523 & 0.6387 & 0.6323 & 0.5567 & 0.6998 \\ 3.7101 & 1.0000 & 1.9313 & 1.3063 & 1.2207 & 2.2456 & 1.6388 & 1.6781 & 2.3696 & 2.3460 & 2.0653 & 2.5964 \\ 1.9211 & 0.5178 & 1.0000 & 0.6764 & 0.6321 & 1.1627 & 0.8486 & 0.8689 & 1.2269 & 1.2148 & 1.0694 & 1.3444 \\ 2.8402 & 0.7655 & 1.4785 & 1.0000 & 0.9345 & 1.7191 & 1.2546 & 1.2846 & 1.8140 & 1.7960 & 1.5811 & 1.9876 \\ 3.0392 & 0.8192 & 1.5820 & 1.0701 & 1.0000 & 1.8395 & 1.3425 & 1.3747 & 1.9411 & 1.9218 & 1.6918 & 2.1269 \\ 1.6522 & 0.4453 & 0.8600 & 0.5817 & 0.5436 & 1.0000 & 0.7298 & 0.7473 & 1.0552 & 1.0447 & 0.9197 & 1.1562 \\ 2.2639 & 0.6102 & 1.1784 & 0.7971 & 0.7449 & 1.3702 & 1.0000 & 1.0240 & 1.4459 & 1.4315 & 1.2602 & 1.5843 \\ 2.2109 & 0.5959 & 1.1509 & 0.7784 & 0.7275 & 1.3382 & 0.9766 & 1.0000 & 1.4121 & 1.3980 & 1.2307 & 1.5472 \\ 1.5657 & 0.4220 & 0.8150 & 0.5513 & 0.5152 & 0.9477 & 0.6916 & 0.7082 & 1.0000 & 0.9901 & 0.8716 & 1.0957 \\ 1.5814 & 0.4262 & 0.8232 & 0.5568 & 0.5203 & 0.9572 & 0.6985 & 0.7153 & 1.0100 & 1.0000 & 0.8803 & 1.1067 \\ 1.7964 & 0.4842 & 0.9351 & 0.6325 & 0.5911 & 1.0873 & 0.7935 & 0.8125 & 1.1473 & 1.1359 & 1.0000 & 1.2571 \\ 1.4290 & 0.3852 & 0.7438 & 0.5031 & 0.4702 & 0.8649 & 0.6312 & 0.6463 & 0.9126 & 0.9036 & 0.7955 & 1.0000 \end{bmatrix}$$

Now using Mathematica software,eigenvectors and eigenvalues for each of the part are attained,according to equation 5.

$$\text{Eigenvalues}[a] \quad (5)$$

The eigenvectors and eigenvalues relative to the maximum eigenvalue(λ_{max}) are presnted in table 2

.

Table 2.
Eigenvalues and eigenvectors of CNG system`s parts pair comparison matrix

	Normalized eigenvectors	***eigenvectors***	***Eigenvalue***
W_1	0.010874	0.1305	$\lambda_{max} = 12.000$
W_2	0.0403459	0.4842	-0.0000813388+0.000042003i
W_3	0.020891	0.2507	-0.0000813388-0.000042003i
W_4	0.03088625	0.3706	0.0000676155+0.0000414148i
W_5	0.03305	0.3966	0.0000676155-0.0000414148i
W_6	0.017967	0.2156	0.0000572791+0.0000220286i
W_7	0.024619	0.2954	0.0000572791-0.0000220286i
W_8	0.024043	0.2885	$-2.38002*10^{-6}$+0.0000466114i
W_9	0.017027	0.2043	$-2.38002*10^{-6}$-0.0000466114i
W_{10}	0.017197	0.2064	$-0.000022273+8.91057*10^{-6}i$
W_{11}	0.019535	0.2344	$-0.000022273-8.91057*10^{-6}i$
W_{12}	0.01554	0.1865	$4.02022*10^{-6}$

The normalized eigenvector for each criterion shows the order of importance of that criterion comparing to the other criteria. The results are presented in table 3.

Table3.
CNG system`s parts in order of importance

priority	part	final weighted index
1	Steel pipes	0.040346
2	Safety valve	0.033050
3	Connection nut	0.030886
4	solenoid	0.024619
5	regulator	0.024043
6	stepper	0.020891
7	Feeding valve	0.019535
8	tank valve	0.017967
9	electrical circut wires	0.017197
10	ECU	0.017027
11	Mixer	0.015540
12	tank	0.010874

CONCLUSION

In orther to specify the influence rate of each CNG system parts on automobile safty,a model was presented.To identify the important parts according to experts opinions feedback,a lot of repeated opinoions that could cause confusion or misleading have been omited. The results were reached through the process of accessing to priority criterias and identification of each part`s level of importance in accordance to Delphi method steps, are desireble and reliable.

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THE BASIS FOR A FLUID INTEGRITY NCAP RATING

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ABSTRACT

The frontal crash mode accounts for about half of the fires in FARS and NASS. Rollovers account for about 25% of the major fires in NASS and carry the highest risk of fatality in FARS fires. In NASS, the vast majority of fires that occur in frontal and rollover crashes originate underhood. Many of these fires eventually engulf the occupant compartment. Incapacitation and entrapment of occupants are important survival factors when underhood fires occur. Tests of several vehicles under operational conditions indicated that the surface temperature of the exhaust manifold and catalytic converter can exceed the ignition temperature of many underhood fluids. NCAP tests should include leakage measurements of all fluids. If leakage is observed, ratings could be assigned based on the amount and flammability of any fluid leakage. Since rapid egress is needed when fire occurs, the force required to open doors should be a basis for the safety rating, as well. Finally, there is technology on-the-road for electrical disconnects of the fuel pump and battery. These features should be evaluated as part of the NCAP test.

INTRODUCTION

FMVSS 302 regulates the flammability of interior materials in passenger cars, multipurpose passenger vehicles, trucks, and buses. It became effective on September 1, 1972. The intent of FMVSS 302 was to reduce deaths and injuries to motor vehicle occupants caused by vehicle fires, especially those originating in the interior of the vehicle from sources such as matches or cigarettes. At the time that FMVSS 302 became effective Goldsmith estimated that 30% to 40% of vehicle fires originated in the interior (passenger compartment and trunk) [Goldsmith, 1969]. That percentage has decreased to less than 10% over the past few decades [Digges, 2005a and 2005 b]. Meanwhile, and the amount of combustible plastics and composites has increased from 20 lbs per vehicle in 1960 [NAS, 1979] to 200 lbs in 1996 [Abu-Isa, 1998 and Tewarson, 1997] and is over 300 lbs today [Tullo, 2006]. Combustible plastics constitute the major fire load (twice the weight and heat content of the gasoline) in a modern motor vehicle and combustion of these materials is the major cause of death in impact-survivable crashes [Bennett, 1990; FMRC, 1997; Ragland two ESV papers, 1998; USFA, 2002; FEMA , 2003; Friedman 2003 and 2005; Ahrens, 2005].

After FMVSS 301 was published in 1972, the focus of regulatory activity in vehicle fire safety has been on improving fuel tank integrity in a crash. The most recent upgrade phased in by September 2008 increased the severity of the rear and side crash tests. Many of the 1996 through 1998 vehicles analyzed already met the higher rear impact standard, based on the sample of vehicles tested [Ragland, two ESV papers, 1998].

The materials inside the occupant compartment that comply with FMVSS 302 provide little fire resistance when subjected to the heat load from a fuel tank or underhood fire. Burn tests from the GM/DoT research indicated that the occupant compartment became untenable within a few minutes of the flame penetration [Tewarson, October 2005 and Digges, 2007d].

In recent model vehicles, the vast majority of the fire cases in FARS are from fires in frontal crashes and rollovers. The frequency of these fires has increased during the past 10 years [Digges, 2008]. Research by MVFRI has shown that a number of innovations have been introduced by vehicle manufacturers to improve fire safety. Some of these improvements will be summarized in this paper. The purpose of this paper is to recommend that NCAP provide consumer information on these fire safety improvements in order to provide broader incentives for their use.

FIRES IN FATAL CRASHES BASED ON FARS

FARS is a census of fatal crashes that occur on public roads. FARS assigns the Most Harmful Event (MHE) to vehicles involved in crashes that involved a fatality. During this evaluation, passenger vehicles were analyzed including cars, pickups, SUVs, minivans and large vans. This excludes motorcycles or other 2 wheeled vehicles, and large trucks and buses. With the exception of rollovers, crash mode was defined using the location of principal damage or principle impact point which is the damage area on the vehicle that produced the most severe instance of injury or property damage. Rollover crashes are defined as an event where one or more vehicle quarter turns occurs regardless of the coded most harmful event. Most of the rollovers have damage to the front or sides of the vehicle. This damage may have been caused by impacts with fixed or non-fixed objects before or during the rollover. In some cases, these impacts may have been the cause of the fatality.

The figures to follow show the five year moving averages for the FARS years beginning in 1979 and ending in 2007. Figure 1 shows the FARS fire rate in passenger vehicles where at least one fatality occurred. The vehicle exposure per billion vehicle miles traveled (VMT) is the denominator. The upper (blue) curve represents fatalities in vehicles with fires. The lower (red) curve represents fatalities in vehicles with fire as the most harmful event (MHE). The fire as MHE applies to the vehicle not the persons in the vehicle. Consequently, there is no certainty that the fatalities were associated with the fire rather than the crash forces. However, death from the fire is more likely for this population.

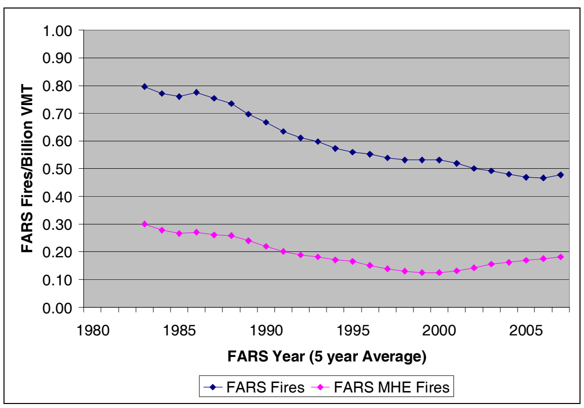

Figure 1. Fatalities in Vehicles with Fires and in Vehicles with Fire as the Most Harmful Event per Billion Vehicle Miles Traveled Annually - FARS

The distributions of annual fatalities and fatalities where fire was the MHE are shown in Figures 2 and 3.

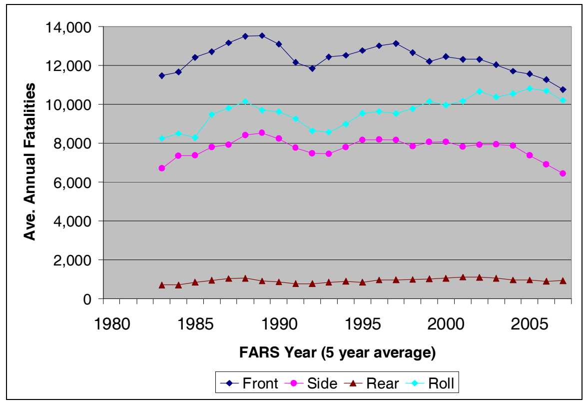

Figure 2. Average Annual Fatalities by Crash Damage Location – FARS 1979 to 2007

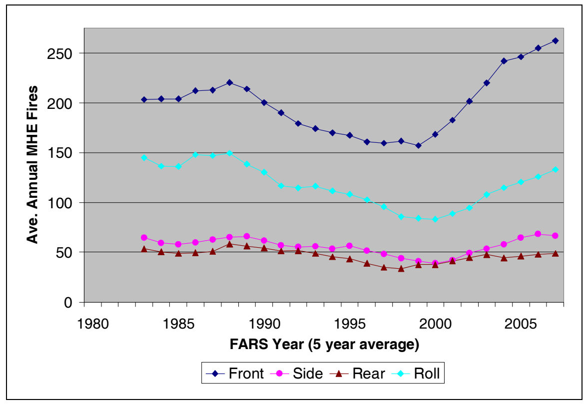

Figure 3. Average Annual Fatalities when Fire was Most Harmful Event by Crash Damage Location – FARS 1979 to 2007

Table 1 shows the distribution of fatalities in FARS years 2000 to 2007 where fire was the most harmful event. The distribution is broken down by the most severe crash direction and rollover is also identified if it occurred during the sequence of crash events.

The entrapment rate for FARS crashes fire as the most harmful event was 23% [Digges SAE 2005]. Based on FARS reported rescue times, 25% of the rural crashes require more than 24 minutes from crash to rescue. [Digges, ESV 2005].

Table 1. Distribution of Average Annual Fatalities when Fire was Most Harmful Event by Crash Type and Damage Location – FARS 2000 to 2007

Damage Location	No Roll	Rollover	Total
Non-Collision	0.6%	8.9%	9.5%
Front	37.6%	11.9%	49.5%
Right	11.2%	2.9%	14.1%
Rear	3.2%	1.4%	4.6%
Left	12.8%	2.8%	15.6%
Top	0.5%	3.1%	3.6%
Undercarriage	0.2%	0.7%	0.9%
Unknown	0.7%	1.5%	2.3%
Total	66.8%	33.2%	100.0%

FIRES IN TOW-AWAY CRASHES BASED ON NASS/CDS

NASS/CDS characterizes fires as either major or minor. A minor fire is an external fire that does spread to the occupant compartment or an occupant compartment fire that does not spread to the entire compartment or to other vehicle compartments.

NASS/CDS defines a major fire as the following situations:

- Total passenger compartment fire
- Combined engine and passenger compartment fire (either partial or total passenger compartment involvement)
- Combined trunk and passenger compartment fire (either partial or total passenger compartment involvement)
- Combined undercarriage and passenger compartment (either partial or total passenger compartment involvement)
- Combined tire(s) and passenger compartment (either partial or total passenger compartment involvement)

About half of the fires in NASS/CDS are major fires [Digges, 2007a] Major fires are more likely to produce serious burn injuries and are the subject of the analysis to follow. The data was published in a report prepared for MVFRI [Kildare, 2006].

Entrapment was recorded in 15% of NASS major fires where entrapment status was known [Digges, 2007b]. An examination of the crash severity at which entrapment occurs was investigated for all NASS cases, including those with no fire. For frontal, side and rear crashes with no fires, 50% of entrapments occurred at crash severities less than 17 mph. For far-side crashes the delta-V for 50% entrapment was 20 mph [Digges, ESV 2005a]. These results suggest that occupant entrapments can occur in relatively low severity crashes. For NASS entrapped occupants, 58% had AIS 3+ injuries [Digges, SAE 2005b]

Table 2 shows the distribution of NASS major fires by crash mode. As in FARS, the frontal and rollover crash modes comprise the largest percentages. Table 3 shows a further examination of the fire origin documented for these most frequent crash modes. The engine compartment is the most frequent fire source in both of these crash modes. Earlier studies reported that no fuel leakage was noted for most engine compartment fires [Digges, 2005b].

Table 2. Distribution of Major Fires by Crash Mode, Weighted and Unweighted Data NASS 1995/2005

Crash Mode	UNW	WGT
Front	51%	45%
Side	10%	6%
Rear	10%	8%
Rollover	21%	29%
Other/Unk	9%	13%

Table 3. Origin of Major Fires, Weighted and Unweighted Data NASS 1995/2005

Fire Origin	Front UNW	Front WGT
Engine Compartment	83%	90%
Fuel Tank	4%	1%
Other	13%	9%
Unk	4%	1%
	Roll UNW	Roll WGT
Engine Compartment	53%	50%
Fuel Tank	34%	46%
Other	13%	4%
Unk	9%	3%

An examination of rollover cases with fire origin in the engine compartment found that almost half suffered no significant damage prior to the rollover [Digges, 2007]. In most cases, the ignition source for the rollover fires could not be determined from the available case documentation.

There is no coding available for a flammable substance leakage other than motor fuel leakage. Consequently, there may be power steering fluid, brake fluid, coolant, window washer fluid, transmission oil, or oil pan leakage, which was responsible for feeding the fire but was not reported.

The majority of these engine compartment fires are reported as major fires. The cause of major fires is generally difficult to determine because the fire is so destructive to the evidence. Electrical faults and fluid spillage are two sources that have been demonstrated in crash tests.

Damage that caused leakage of power steering fluid was reported to cause engine compartment fires in two identical frontal crash tests [Santrock, 2005]. In these crash tests, the exhaust manifold was at operating temperature and the engine was running.

In another series of crash tests, an engine compartment fire was caused by electrical fault [Jensen, 1998]. The fire was unrelated to spilled gasoline or other engine compartment fluids, except battery acid. The fuel for the fire was provided by the plastic materials near the battery.

These test results suggest that factors that can not be identified by the NASS investigators may be associated with the large number of fires in which no fluid leakage was observed. Technology to prevent electrical faults and leakage of flammable fluids should be beneficial in reducing the incidence of engine compartment fires.

FIRES REPORTED IN STATE DATA

A study initiated by MVFRI examined the characteristics of fires in the police accident records of three states – Maryland, Pennsylvania and Illinois [Friedman, 2005]. The frequency of fires was found to be greatest in frontal impacts across all three states. All states reported a dramatic increase in the frequency and rate of fires in rollover crashes. This effect appeared to be independent of passenger car and SUV distinctions. The incidence of fires in rear impacts appears to be reduced compared to an earlier study by Malliaris [1991].

The Friedman Research Corporation also used state police accident data to examine the frequency of fires in pickup trucks of the same model but with different engines. The data indicated that for some full size pickup models the eight cylinder (V-8) engines had a higher fire rate than the inline six cylinder (I-6) engines [Friedman, 2006]. An obvious difference is the increased exposure of the exhaust manifold and catalytic converters in the V-8. However, the possible relationship between engine type and fire rate was not observed in a model of smaller pickups with V-6 and I-4 engines.

Another significant finding of this study was that pickups equipped with relay-type fuel cut-off switches had a higher fire rate in rollovers than those equipped with inertia switches [Friedman, 2006]. It was assumed that the relay switches used air bag deployment information that may not respond to a pure rollover.

GM TEST RESULTS – TIME TO UNTENABILITY

The GM/DOT Settlement research program in motor vehicle fire safety has been analyzed and synthesized by a team of fire experts led by FM Global. Of particular interest has been the analysis of eleven crashed vehicle burn tests. These tests subjected crashed vehicles to under-hood and spilled fuel fires of an intensity that could be possible after a crash. Three vehicles were subjected to under-hood fires with ignition sources either at the battery location or by the ignition of sprays and pools of mixtures of hot engine compartment fluids from a propane flame located in and below the engine compartment.

Two additional tests were conducted to evaluate countermeasures. The effectiveness of a fire retardant treatment of the HVAC unit was evaluated by tests of engine compartment fires in 2 vehicles with frontal damage. One of the vehicles was tested with the treatment and the other without.

A list of vehicles tested with engine compartment fires is as follows:

1. 1996 Dodge Caravan - front crash and fire started in the engine compartment;
2. 1997 Chevrolet Camaro - front crash and fire started in the engine compartment;
3. 1998 Honda Accord - front crash and fire started in the engine compartment;
4. 1999 Chevrolet Camaro - FR HVAC- front crash and fire started in the engine compartment;
5. 1999 Chevrolet Camaro - non-FR HVAC control-front crash and fire started in the engine compartment;

An in-depth analysis of these tests has been published [Tewarson, 2005, Vol 1]. The objectives of the analysis were to investigate the ignition and flame spread behaviors of engine compartment fluids and polymer parts, to assess time to flame penetration into the passenger compartment and to assess the creation of untenable conditions in the passenger compartment.

For the front crashed vehicle burn tests with ignition in and under the engine compartment, flame penetration time into the passenger compartment varied between 10 to 24 minutes.

Once the flame penetrated the passenger compartment, the environment rapidly become untenable. In some burns, the passenger compartment became untenable before flame penetration. The untenable conditions were due to heat exposure (burns) and exposure to combustion products (toxicity and lethality). The time between flame penetration and untenability of the passenger compartment varied from minus 2.5 to plus 3.2 minutes.

In general, polymeric parts in the engine and passenger compartments burn as molten pool fires with high release rates of heat, CO, smoke, and other toxic compounds, typical of ordinary polymers. Pool fires of the molten polymers are the major contributors to the vehicle burning intensity and contribute towards the penetration of flames into the passenger compartment. The fire retardant treatments of the polymer parts that were tested in the program proved ineffective in delaying fire penetration into the passenger compartment.

ENGINE COMPARTMENT TEMPERATURES

Additional testing has been conducted by Biokinetics and Associates, Ltd. to evaluate under-hood temperatures of different classes of vehicles [Fournier, 2004]. The results showed considerable difference between the maximum temperatures of different vehicles when operated under load. In a standardized uphill test, the maximum temperature measured on the exhaust manifold varied from a low of 241 ^{o}C for a minivan to a high of 550 ^{o}C for a passenger car.

FIRE PROPERTIES OF FLUIDS AND PLASTICS IN THE ENGINE COMPARTMENT

Tewarson has summarized the fire resistance measurements of fluids that are commonly found in the engine compartment. The flash point and hot surface ignition temperatures are summarized in Table 4.

The $\mathbf{T_{flash}}$ variable is the minimum temperature at which a fluid gives off sufficient vapors to form an ignitable mixture in an open cup. The $\mathbf{T_{hot}}$ variable is the minimum temperature of a hot surface to cause ignition of a fluid spilled on the surface. This variable requires a test that was developed by General Motors [Tewarson, 2005, Vol 2].

Table 4. Average Flash and Hot Surface Ignition Temperature of Underhood Fluids

Fluid	$\mathbf{T_{flash}}$ **(^{o}C)**	$\mathbf{T_{hot}}$ **(^{o}C)**
Motor Oil (Petroleum)	134	310
Motor Oil (Synthetic)	160	324
Gear Lubrication Fluid	154	325
Power Steering Fluid	188	312
Automatic Transmission Fluid	163	304
Brake Fluid	123	287
Antifreeze	116	506
Engine Coolants	110	518
Windshield Washing Fluids	32	

The Fire Safety Branch of the FAA and Galaxy Scientific Corp. performed flammability evaluations of 18 automotive plastics using a microcalorimeter at Trace Technologies, Inc. [Lyon, 2006]. The flammability of the underhood plastics tested was similar to the flammability of plastics from the passenger compartment. When compared to plastics used in the interior of aircraft cabins, the automotive plastics were several times more flammable. There was considerable variation in the flammability of plastics used under the hood. Two parameters used to measure flammability were the heat release capacity (HRC) and the total heat release (HR).

The heat release capacity (HRC) is the ratio of the specific heat release rate to the surface heating rate. The HRC is a flammability parameter that is a good predictor of fire performance and flame resistance. High values indicate higher flammability. Testing of 13 plastics used in aircraft passenger cabins produced an average value of 98 J/g-K. Plastics used in aircraft overhead compartments have an average HRC of 216 J/g-K.

The total heat release (HR) is obtained by dividing the maximum value of the specific heat release rate by the heating rate in the test. The HCR and HR values for typical automotive plastics are summarized in Table 5.

Table 5. Heat Release Capacity and Heat Release for Typical Underhood Automotive Plastics

Component Tested	HRC J/g-K	HR kJ/g
Brake Fluid Reservoir	1298	45.3
Resonator Intake Tube	1293	43.9
Battery Cover - black	1280	43
Front Wheel Well Liner	1250	45.3
Battery Cover -transparent	1106	42.9
Resonator Top	966	35.2
Radiator In/Out Tank	514	22.5
Engine Cooling Fan	400	18.6
Power Steering Reservoir	397	19.4
Hood Liner Face	101	7.9
Hood Insulator	96	5.2

TECHNOLOGY FOR FIRE SAFETY

A survey of the fire safety technology that was present in on-the-road vehicles was conducted by Biolinetics and Associates. Ltd. A database of 2003 model year vehicles was assembled and the technologies were documented in a database [Fournier, 2004]. Lists of available fire prevention technologies were summarized in subsequent papers [Fournier,, 2005; and Report R06-20, 2006].

The technologies that were present included:

- Check valves for the tank filler tube
- Roll-over leak prevention valves
- Shut-off mechanisms for electronic fuel pumps
- Crash sensing battery disconnects

It was observed that there was a difference in the extent to which fire safety had been incorporated into the vehicle design. For example, in selecting insulation material for underhood liners there were two orders of magnitude difference in the flammability properties from vehicle to vehicle [Fournier, 2006]. There was no relationship between the cost of the vehicle and the fire resistance of the underhood liner. This result suggests a lack of attention to the flammability of the material may have been a factor that precluded more fire resistant selections.

The analysis of state data suggested that some fuel cut-off systems were better in rollover than others [Friedman, 2006]

Fluid leakage in rollovers was another area where large differences were found among on-the-road vehicles. A research program by Biokinetics investigated and documented the technology in present day vehicles to prevent fuel leakage when lines from the fuel tank are severed [Fournier, R0-6-20, 2006].

Biokinetics conducted leakage tests on 20 fuel tanks to study the fuel containment technologies employed and their performance. The tests simulated a vehicle rollover by rotating a tank, filled to capacity, about an axis that when installed in a vehicle would be parallel to the vehicle's longitudinal axis. The tanks were rotated to seven discreet positions during the rollover simulation. None of the tanks leaked when all hoses were intact. In each position, the fuel system hoses were disconnected one at a time to represent a damaged or severed line and the resulting leaks were observed. The results of the testing showed that six of the tanks leaked in every orientation and ten leaked in some orientations. However, four fuel systems did not leak with one line at a time severed when subjected to all roll orientations. There was no relationship between the cost of the vehicle and the presence or absence of leakage prevention technology. The results of these tests are discussed in more detail in earlier papers [Fournier, R04-06c, 2004; Digges, 2005a].

DISCUSSION OF NCAP PROCEDURES

FARS, NASS and State data all indicate that the most fires in current vehicles originate in frontal crashes and rollovers. About half of the fires are in frontal crashes and a quarter are in rollover. The frequency of fires in rear impacts has been decreasing while fires in frontal crashes and rollovers have been increasing. State data indicates that the rollover fire rate has increased in recent years for passenger cars as well as light trucks and vans. Most major fires in NASS frontal crashes and rollovers originate in the engine compartment.

Many on-the-road vehicles incorporate technology to reduce fires that originate from electrical faults and fluid spillage. However, there is no way for consumers to know of these safety features. Simple modifications to the NCAP tests could provide valuable consumer information as well as rewards for incorporating fire safety technology. The initial focus of the testing should be on frontal crashes and rollovers.

MODIFICATIONS TO THE NCAP TEST PROCRDURE

FMVSS 301 requires a fuel containment test after the crash that subjects the vehicle to rollover attitudes. This test is called the static rollover test. The vehicle is placed in a fixture and rotated in 90 degree increments. At each increment, the fuel leakage is measured. There are no leakage requirements for fluids other than the motor fuel and none are measured.

The first modification to the NCAP test procedure we propose is to expose the test vehicle to the static rollover test before the crash test occurs. The vehicle would be tested in its operational state with all fluids at their recommended levels. The test would evaluate two fire safety features. The first would be a measurement of any leakage of a flammable fluid. The second would be an evaluation of any technology present to disconnect power from the fuel pump and the unfused battery-to-starter connection. . It is also recommend that the static rollover test be performed in 45 degree increments.

The second modification to the test procedure would be to measure the leakage of all fluids after the crash test and determine the degree to which the battery has been isolated. After the crash test, repeat the static rollover and measure all fluid leakage and determine the degree to which the battery is isolated in a rollover. The crash test should be performed with the battery fully charged and the electrical system connected. All of the fluids should be at their recommended levels. It would also be desirable to have the engine hot and running.

It is important for fluids to be present during the crash since they can provide substantial inertial forces to the container and the incompressible nature of these fluids can rupture the container. Engine coolant leakage should not be counted for the frontal crash, but may be counted for the side and rear crashes.

In the event insurmountable safety issues arise from testing with the flammable fluids present and the engine hot and running, less flammable fluids could be substituted as is currently done for the motor fuel in the FMVSS 301 tests. Under these conditions it may not be feasible to run the engine.

A third modification would be to evaluate the force required to open each of the doors. A rating system could be based on the door opening force required relative to the force that could be exerted by a small (5th percentile) female. See Appendix A of [Digges, ESV 2009] for a simple test methodology to determine this force level.

Finally, all fuel and vent lines leading from the tank should be cut or disconnected and fluid leakage should be measured when the vehicle is subjected to the static rollover test. This test would encourage the leakage prevention technology that currently exists in some vehicles to be more widely applied.

Fire safety star ratings could be based on the test results with points awarded for containment of fluids, the functioning of electrical disconnects and the force required to open each door.

CONCLUSIONS

The FARS data shows that in recent years, frontal crashes and rollovers have become an increasing fraction of the total highway deaths in which fire was the most harmful event. State data shows similar trends. An examination of major fires in NASS frontal, side and rollover crashes shows that the vast majority originate in the engine compartment. Fuel leakage was rarely documented in these cases.

It is probable that under-hood spilled fluids other than gasoline may be a principal source of the engine compartment fires. Tests of several vehicles under operational conditions indicated that the surface temperature of the exhaust manifold can exceed the hot surface ignition temperature of many underhood fluids. However, the frequency and extent to which these flammable fluids leak in crashes can not be determined from accident data because the fire destroys the evidence. Crash tests have shown that leaking power-steering fluid and battery faults are both possible sources of engine compartment fires.

Investigations of on-the-road vehicles has shown that extensive fire safety technology has been incorporated in some vehicles, but not others. There is some evidence of lack of attention rather than cost of countermeasures is an impediment to safety improvements.

The fire safety features of fuel pump and battery disconnect should be evaluated while the vehicle is exposed to a static rollover test before and after the crash test. In addition, the ease of egress from the vehicle should be evaluated after the crash test.

Finally, it is proposed that future NCAP tests include leakage measurements of all fluids. If leakage is observed, ratings could be assigned based on the amount and flammability of the fluid leakage. Fluid containment, electrical isolation, and ease of egress should be the basis for a star rating of fireworthiness.

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FUTURE E/E-ARCHITECTURES IN THE SAFETY DOMAIN

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ABSTRACT

The number of functionalities, sensors and control units in modern vehicles is increasing permanently. In spite of this, the OEMs aim to minimize these numbers to reduce complexity, effort and cost. Thus it is very important to find the most suitable E/E-architecture jointly with the OEM in order to cope with these challenges. Furthermore, the re-partitioning of content in the safety domain offers great opportunities for the OEM.
First of all, it can reduce the overall costs, since the trend towards increasing active and passive safety systems offers synergies of components and functions:
Driven by legislation, the installation rates of safety features like ESP® will rise significantly in some regions. Together with the fact that airbag systems in the triad markets have a take rate of almost 100% it is clear that there will be high potential in developing cost effective E/E-architectures.
Consequently two main steps are necessary to cope with these challenges: The first step is finding a suitable integration concept for inertial sensors on the vehicle architecture level. The second step is cost optimization by using maximum synergies or high-integration concepts.
Beyond cost reduction, the current functionality can be improved since the inertial sensors are directly connected on the same PCB-board with the airbag-algorithm controller in some integration concepts. This gives the possibility to feed the airbag-algorithm with inertial sensor data like for example the yaw rate. This yaw rate can be used in a yaw rate based airbag algorithm to further improve the performance.
This paper gives an overview about the architectures and functions, discusses the pros and cons of the different concepts and gives an outlook for future systems.

INTRODUCTION

Approximately 40,000 people are still killed every year in the European Union [1]. Also in North America the number of traffic fatalities is too high. In 2001, the European Commission has stated the goal to achieve a 50% reduction of the traffic fatalities by 2010. By end of 2007 a significant reduction of 24.6% has been reached [2]. This is a clear progress, but without further increase of effort, the goal of 50% will not be achieved.
Important means to realize higher safety in public transport are the introduction of active and passive safety systems into the passenger cars. As passive safety systems we understand systems which reduce the consequences of an accident. Injuries will be reduced in severity and fatalities partly avoided, e.g., by use of safety belts and airbags. Active safety systems, however, mitigate the crash severity or even avoid the crash by stabilizing the vehicle in critical situations, shorten the braking distance, and avoid skidding, e.g., by electronic stability program (ESP®).
These safety functions are proven to be helpful to increase safety in the vehicle. However, they increase the number of electronic control units in the vehicle and therefore increase complexity and cost.
For more than ten years, new vehicles are equipped with passive safety as standard equipment in Germany. Together with the very high acceptance of the most important passive safety device - the safety belt - these systems have achieved a very high distribution in road traffic. As a consequence, the number of traffic fatalities has been significantly reduced, together with other factors by more than 32%, in spite of an increased mileage per person. The high market penetration of passive safety systems in Germany and Europe is due to legislation as well as to the work of consumer test organizations.
Active safety functions are far less abundant in the vehicles on the road. However, also these systems are beginning to gain effectiveness through higher take rates due to legislation (e.g., in the U.S. for newly released vehicles from 2012) and consumer test organizations (e.g., EURO-NCAP, safety rating)

Safety functions and E/E architecture of the vehicle

The introduction of additional safety systems into the vehicle increases the number of electronic control units and therfore also weight, energy

consumption, complexity, and costs. Safety functions will develop high effectiveness when they are introduced as standard equipment. In this case an optimized solution with respect to cost, weight, and energy is needed.
Analyzing the possibilities of architecture development reveals that the optimization of the E/E-architecture can mean that the current borders between active and passive safety have to be eliminated. Some improvements and cost reductions can only be realized if active and passive safety systems are merged to a safety domain in the passenger car.
In consequence, three different E/E-architectures are currently developed as optimized vehicle architectures in respect to integration of the inertial sensors for vehicle dynamics control. Today these sensors are ideally mounted close to the center of gravity. The three different integration approaches are:

- Integration into the brake control unit: ESP®i
- Integration into airbag control unit: AB*plus*
- Integration into a domain control unit with functional extensions: (DCU)

The three architecture variants offer characteristic advantages in respect to cost, weight, packaging and energy consumption, as well as possible sensor synergies, raising the question: Which of the solutions is the best one? As so often, the answer is not a simple and general one. Therefore an analysis of the systems with pros and cons is given below, providing a basis for making the correct decision in specific projects.

Architecture Variants

ESP®i

The ESP®i control unit is a standard ESP® control unit with integrated inertial sensors. This means that the sensors which are usually mounted separately in the central ESP®-Sensor cluster are now integrated in the ESP® control unit, located directly at the hydro aggregate. Therefore, the separate ESP® sensor cluster can be omitted. Since in the ESP®i architecture no connection to another system is necessary, it is an independent system. An ESP®i system usually covers the base functions like ESP®, hill hold control (HHC) and hill descend control (HDC).

AB*plus*

An AB*plus* control unit offers all functionalities with respect to state of the art crash sensing for passive safety: front, side, and rear crash detection. Furthermore, rollover detection, precrash functionality and pedestrian protection can be realized optionally. As described recently [3], the

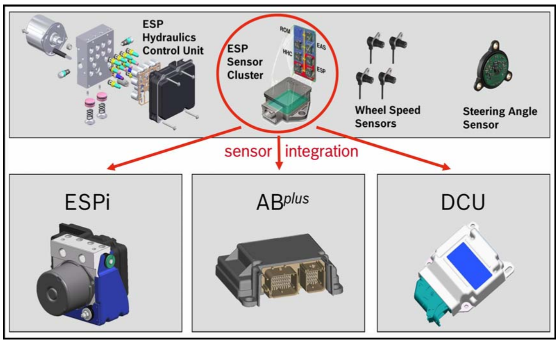

Figure 1: Overview of integration concepts for inertial sensor cluster function. ESP®i and ABplus mean integration into another existing Electronic Control Unit (ECU), DCU allows for high flexibility in functional extension.

inertial sensors for vehicle dynamics control of the ESP®-system are additionally integrated into this airbag control unit. Usually these sensors are located in a separate sensor cluster which is ideally mounted on the vehicle tunnel close to the center of gravity. With the AB*plus* approach this additional ESP® sensor cluster can be omitted. The integrated angular rate and acceleration sensor data are broadcasted via CAN interface to the brake ECU. The data are used in the brake system to prevent the vehicle from instable driving situations. Once the interface between the ESP® system and the airbag system is established, ESP®-based CAPS (combined active and passive safety) functions can be realized with a reduced networking effort.
AB*plus* is available in a variety of configurations. In addition to the standard AB*plus* version with integrated ESP® sensors, AB*plus roll* offers additional sensors for rollover mitigation and protection. The configuration AB*plus 6D* contains a complete set of angular rate and acceleration sensors for all three dimensions. In addition to ESP® and rollover protection, it can also support chassis control functions like active damper control.

DCU

The Domain Control Unit (DCU) is a scalable central software and hardware integration platform in the vehicle. The functionality can be compared with a network server in the computer world. By analyzing all vehicle movements with the integrated inertial sensors, the DCU is the ideal home for all applications with high requirements like "Vehicle Motion and Safety" (VMS) and "Vehicle Dynamics Management" (VDM).
A VDM function allowing for steering control on the basis of ESP® data can still be calculated by the ESP® ECU, but the networking of ESP® with damper, chassis and drive train requires more computing power which can be provided by the DCU.

Equipped with a powerful controller, the DCU is highly scalable and contains inertial sensors up to all three axes. That means low-g acceleration sensors as well as angular rate sensors. The system is also capable of integrating redundant sensors if required. Additionally, a DCU can also include the typical high-g acceleration sensors and angular rate sensors used for passive safety.
To measure the vehicle motion, the optimum position of the DCU is close to the center of gravity of the vehicle right on the vehicles transmission tunnel.
In the case of integrated passive safety sensors, the DCU is connected via PSI5 interfaces to the airbag control unit which does not contain sensors anymore. The relevant sensor values for the occupant safety function are sent by the DCU. Since the airbag control unit has no internal sensors left, the mounting requirements about fixation, orientation and geometry are reduced. Consequently there is no need for a special mechanical transfer function from the fixation points via housing and PCB to the sensor element. With this, the airbag control unit does not necessarily have to be located on the tunnel, but can be mounted at any position within the passenger compartment where the space is less limited.

Drivers for selection of optimum architecture

Market view

Three different solutions are available to be selected as E/E architecture of the vehicle. As the requirements and the decision of the architecture depend on the functional requirements it is important to analyze the market situation for active and passive safety systems.
Passive safety and its functionality are strongly driven by consumer tests and legislation. The status is that in Europe, North America and Japan, basically all newly released vehicles are equipped with standard airbag functionality. Increasing number of restraints and control loops is seen with increasing vehicle price and standard. The airbag system with front crash protection is basic functionality.
Side crash becomes more and more standard in B and C segment, whereas roll over protection is additionally offered in convertibles and Sport Utility Vehicles (SUVs), as well as vehicles of the D and E segment.
The active safety in form of ESP® on the other side is currently still not standard equipment even in Europe in many vehicles of the A and B segment. Starting with the C-segment the take rate of ESP® in newly bought vehicles is strongly increasing in Europe. In the E and F segment additional driver

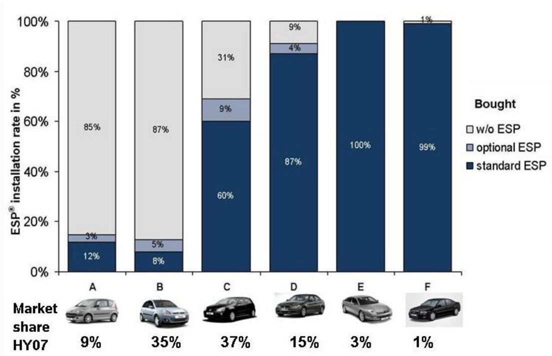

Figure 2: ESP® installation in major European markets (D, F, I, ES, UK) 2006 by car segment – optional and standard equipment. Source: Bosch figures in installation rates by new car registrations.

assistance functions extend the functionality of the active safety.
Looking at the vehicle segments, we find that the different classes are not equally equipped with the safety features of active and passive safety. Starting with basic passive safety without active safety we find a lot of vehicles in the A and B segment. Increasing equipment with active safety in form of ESP® and passive safety with side crash protection is found in C and D class. In the upper segments passive safety and active safety are standard, further functions of driver assistance and comfort are also extending the functionality of the active safety in these passenger cars.
These relations between active and passive safety are quite different in the other important markets of the world. Legislation activities and consumer test organizations also have influence on the distribution and development of the markets. Thus the analysis is necessary to be done for the specific target of the vehicle as a product.

Functional view

Because of the optimized functionality and the big advantage of being an independent system, the ESP®i architecture finds its main market volumes in the vehicle segments A-C, mainly addressing the span from the mini class up to the medium class. Especially small vehicles with limited functionality and ESP® installation rates below 100% are the ideal candidate for ESP®i, since this ESP® system is not interacting with other networking partners like the passive safety system.
The AB*plus* architecture typically has the main volumes in medium class vehicles from segment B to E, similar to the standard architecture with a separate ESP® sensor cluster. This is easy to understand since both cover the same technology

and the technical features are the same, the difference in many cases is only the housing.
An additional main focus for AB*plus* is in the vehicle segment G and H which cover the pick-ups, SUVs and vans. Especially in the US these segments are often equipped with AB*plus* since ESP® will be mandatory in 2012 and a roll over legislation is expected as well. Therefore an AB*plus roll* with standard ESP® and rollover mitigation and protection is a smart solution to cover the requirement at lowest costs. Since AB*plus* uses the standard technology known from the separate sensor cluster the technical risk is also very low. Sensors synergies are possible in this architecture, where active and passive safety are connected and exchange data.
The DCU provides a fully AUTOSAR compatible software integration platform with an enormous controller power where a lot of functions can be integrated very easily. From damper control over active front steering up to a complete domain control the DCU offers a lot of opportunities to even integrate a lot of customer specific AUTOSAR software modules. Therefore it is clear that the DCU covers a broad band over the segments with main volumes in the D to F segment, which range from the upper medium class up to the luxury class.

Introduction of extended functions: Vehicle Motion Observer

Besides the trend towards new E/E architectures and different hardware/software integration concepts, there is a strong drive to integrate inertial sensors. Low-g acceleration and roll rate sensors around all three axes (so called 6D sensing systems) are the enabling technology for new powerful features: Based on the acceleration signals and roll, pitch and yaw rate the trajectory of the vehicle as a rigid body model can be described and measured very precisely in space. This gives the opportunity to create a so called “Vehicle Observer”, an algorithm which calculates important parameters of motion. The Vehicle Motion Observer (VMO) therefore provides a platform for improving and developing innovative functions for the domains of safety, agility and comfort.
Based on theory a motion of a vehicle, which in first order can be seen as a rigid body, can be described by kinematic and kinetic differential equations. With the input values from the 6D inertial sensors, the different wheel speeds and the steering wheel angle the VMO computes besides processed 6D signals a sideslip angle, roll and pitch angles as well as different vehicle velocities. Additionally other vehicle parameters like the mass and information about the driving environment (road) and situation is available. Solving the rigid body differential equations in combination with Kalman-filtering is state-of-the-art for aviation. Nevertheless these algorithms are complex and need a lot of computational power. Therefore the VMO can be easily integrated in a powerful computer platform like the Domain Control Unit (DCU). Standard estimator algorithms are usually model based, this means the tire and vehicle model influences the results. The model uncertainties and the sensitivity with respect to parameter variation limit the accuracy of the estimation especially during high dynamic maneuvers the estimation is not accurate. The VMO based on the 6D computation has the big advantage that the rigid body differential equations give an exact kinematic relation, so the values can be computed exactly. This approach is independent from any vehicle or tire model and does not depend on other vehicle parameters. Since the VMO calculates instead of estimates output values the equation results are robust against parameter variation.
The determination of vehicle ego motion implies the computation of vehicle velocities vx, vy, vz, sideslip, roll and pitch angle as well as inertial sensor signal processing like offset, orientation and gravity compensation, filtering and differentiation. The improved quality and reliability of the ego motion enables new functionality. On the other hand the quality of environment recognition (banked curves, slopes and friction coefficient) and of driving situation (over and under steering) are improved compared to conventional estimation techniques. Furthermore the vehicle mass and the center of gravity can be estimated precisely with the VMO. Therefore the VMO enables new and more precise functionalities.

Current crash sensing strategy and potential of yaw rate data to increase performance and functionality

In a vehicle crash, the activation of restraint devices is basically defined by crash type and crash severity. Both, the crash type and the crash severity to be expected are nowadays evaluated by the combined analysis of signals from acceleration, roll rate and pressure sensors. In high performance systems, surround sensing sensors (e.g. radar) can be integrated in the vehicle also providing data for the passive safety system.
The acceleration sensors serve to evaluate the acceleration signal waveform and the velocity change in the longitudinal and lateral directions. With the roll rate information, a prediction of a vehicle’s rollover movement can be evaluated. By means of the pressure sensors, side crash events with deformation of the doors are rapidly

recognized and classified. The surround sensing system serves to detect relative velocities of approaching objects and estimate the time-to-impact (TTI) as well as the overlap.
Current sensor configurations and evaluation algorithms are designed and applied on the basis of typical single crash scenarios. An integral part of the corresponding restraint system tests are separated into pure front, side and rollover scenarios. In general, the total kinetic energy of the vehicle and the crash opponent is converted to deformation energy due to the linear deceleration.
The combined observation of linear acceleration and yaw rate has so far been of minor importance for crash classification. In a real world crash situation, however, the combination of the linear acceleration and yaw rate changes of the vehicle are expected to occur frequently during a crash. Typical scenarios with high yaw rate are low overlap crashes or non-centered crashes. For these crash scenarios, the longitudinal and lateral acceleration together with the yaw rate signal adequately describe the vehicle movement during the crash. Detailed analysis of the data reveals crash type and crash severity in real world crash situations in terms of impact point and impact direction with respect to the vehicle's center of gravity.
While a full frontal crash may reveal high longitudinal deceleration and no yaw rate signal at the point of time where activation of restraint systems is required, offset crashes of similar severity may reveal much lower longitudinal deceleration but high alteration of yaw rate close to the optimum activation point.
Today, the integration of a large number of restraints (with different levels of requirements for deployment decision) allows a better adaptation in real world crash scenarios. The application of force to the vehicle during the crash has a substantial influence on the movement of the vehicle, and therefore of the occupant. The activation of the various restraints is to be optimized for the relative movement of the occupant in a specific crash. This especially applies to the case of combined linear and alterations of yaw rate. While absolute value and duration of linear acceleration defines average crash severity, the yaw acceleration defines the variation of crash severity within the vehicle. A crash impact causing high rotational energy may lead to a moderate acceleration close to the vehicle's center of gravity, but a significantly higher acceleration value at places with larger distance to the vehicle's center of gravity.
The yaw rate crash sensor is supposed to play an important role in the correct classification of real world crash scenarios, where crash adaptive use of various restraints may increase the effectiveness of the vehicle's safety system.

CONCLUSIONS

All three architecture variants AB*plus*, ESP®i and DCU are available to improve the E/E-architecture in the vehicle. Optimization for cost and weight, with optimized conditions for increased safety and environmental sustainability is possible.
Since safety standards are different due to regionally determined legislation and market situation, as well as the distribution of functional requirements in the different vehicle types, a complex situation in respect to the requirements in current vehicle projects is the consequence. With respect to the question of optimum E/E-architecture it is clear that a general answer cannot be given. The optimum solution can be found, if these boundaries and conditions are taken into account. Together with the effects on vehicle level, project aspects, and organizational implications the E/E-architecture can be optimized for vehicle types and platforms.

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ISO 27956 - A NEW STANDARD DESCRIBING REQUIREMENTS AND TEST METHODS FOR LASHING POINTS AND PARTITIONING SYSTEMS FOR CARGO SECURING IN DELIVERY VANS

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ABSTRACT

According to the German Road Traffic Regulations, the cargo has to be secured in a vehicle so that it will not move, fall down, roll around, be shed or generate avoidable noise. This is required under normal conditions of operation including full braking, emergency braking, braking in a curve, fast lane changing and driving in a curve. The basis for a proper securing of cargo in delivery vans (N_1-vehicles) includes a robust partitioning system which fully or partially separates the occupant compartment from the loading space, as well as lashing points. The partitioning system retains the cargo during braking, for example. Lashing points serve to hold lashing devices to secure the cargo, e.g. lashing straps for tie-down lashing.

In Germany, partitioning systems and lashing points for commercially employed new vehicles covered by the scope of the Accident Prevention Regulation for Vehicles (BDG D29) have been mandatory since 1996. DIN 75410-3 “Securing of Cargo in Truck Station Wagons (Closed Body)”, did apply here as the national technical regulation.

In order to anchor the tried-and-tested requirements regarding partition systems and lashing points in globally applicable regulations, the ISO/TC22/SC12 set up the workgroup WG9. On a voluntary basis non-governmental organisations and OEMs created the standard ISO 27956. As a result the national standard has not only been transferred into English but has also been further developed now. As the drafts ISO/CD 27956 and ISO/DIS 27956 were received favourably after their worldwide ballots, the final standard ISO 27956 has been approved now and will be published in the spring of 2009.

The paper will report on the necessity and the background as well as on the contents of this standard which may be used for self certification, for example. Prospects of further development of the Standard to cover latest additional equipment for load securing in delivery vans will be given as well.

INTRODUCTION

Lashing points and partitions as devices fitted to closed-body vehicles as a means of securing cargo are required in the German national standard DIN 75410-3. It first appeared in April 1996. Since October 1996 this standard stipulated the obligation for lashing points and partitions in all new vehicles covered by the Accident Prevention Regulation “Vehicles” (BGV D 29, Section 22 Sub-section 1, formerly VBG 12) [1] in Germany. This are in principle all commercially used vehicles.

Accidents and daily practice were the cause for the first version of the standard to be subjected to a renewed revision and for some requirements to be formulated more precisely. The calls to correspondingly raise the requirements of the previous standard have been generally supported by the German workgroup responsible for the standardisation committee for motor vehicles at VDA (German Association of the Automotive Industry). This led to the current version of DIN 75410-3, which is valid since October 2004 [2, 3].

In order to embed the now tried-and-tested requirements for partitions and lashing points in the globalised markets, the ISO/TC22/SC12 set up the workgroup WG9 in January 2006. Its remit included converting the standard DIN 75410-3 into the international standard ISO 27956. The original contents of the national standard were subjected to further development again and the first draft ISO/CD 27956 was completed in October 2007. After taking into consideration the received comments the revised second draft ISO/DIS 27956 was published in April 2008. After the approval of the final version of the standard ISO 27956 “Road Vehicles – Securing of Cargo in Delivery Vans – Requirements and Test Methods” it will be published in the spring of 2009 [4].

This paper reports on the necessity and the historic background as well as on the contents of the standard (scope, definitions, requirements and tests). Furthermore, reference will be made to previous experience and to the prospects of further development of the standard.

METHODS OF CARGO SECURING AND LOAD ASSUMPTIONS

In Germany the VDI guideline 2700 ff is one of the basic regulations concerning the securing of loads on road vehicles [5]. An example of international regulations would are those set out in the European Best Practice Guidelines on Cargo Securing for Road Transport [6]. An example of specific regulations for an industrial loader for securing cargo for transport by load carriers on commercial vehicles which covers road transport with vans is the guideline for the interfactory transport by Daimler AG [7]. At the moment, the Guideline VDI 2700 - Sheet 16, which describes in detail the securing of cargo in vans (transporters) up to 7.5 t Gross Vehicle Mass (m_{GVM}), is only available in a draft version [8]. This guideline is intended for forwarders, freight carriers, loaders, vehicle owners, vehicle drivers and all those who the law, ordinances, contracts or other regulations deem responsible for securing the cargo and ensuring safe transport. In other words: Guideline VDI 2700 – Sheet 16 regulates the practical execution of cargo securing measures in vans (transporters). The guideline also defines in its scope that it applies to all vans up to 7.5 t m_{GVM}, irrespective of whether they are fitted with a closed body, box-type body or platform superstructure, and to any hitched trailers. In contrast to this, ISO 27956 (or DIN 75410-3) describes the requirements for the vehicle devices intended to secure the cargo in delivery vans (closed-body vehicles) and the associated test methods.

The VDI 2700 ff states basic load assumptions for cargo securing. For the commercial vehicles referred to here, it has hitherto been the case that, when regard the securing of cargo, a longitudinal deceleration of the vehicle forwards of 0.8 g (emergency braking) as well as an acceleration laterally left or right (cornering, sudden swerve and lane change) as well as in rearward direction of 0.5 g had to be assumed. Sheet 16 was the first to define greater load assumptions for lighter vans corresponding to their driving dynamic properties, Figure 1. For instance, for a vehicle with a permissible total mass of over 2.0 up to 3.5 t, the minimum inertia force of the cargo in the forward direction is 0.9 times and laterally 0.7 times its weight force.

Gross Vehicle Mass (m_{GVM})	**up to 2.0t**	**more than 2.0t up to 3.5t**	**more than 3.5t**
Inertia force in frontal direction	$0.9 \cdot F_G$	$0.8 \cdot F_G$	$0.8 \cdot F_G$
Inertia force in rearward direction	$0.5 \cdot F_G$	$0.5 \cdot F_G$	$0.5 \cdot F_G$
Inertia force in sideward directions	$0.7 \cdot F_G$	$0.6 \cdot F_G$	$0.5 \cdot F_G$

Examples of inertia forces for a gross vehicle mass of more than 2.0t up to 3.5t

F_G: Force of gravity of the cargo

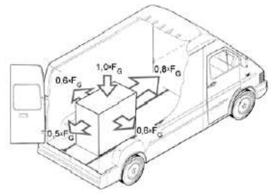


Figure 1. The minimum mass forces to be taken into account for standard operation in accordance with VDI 2700 – Sheet 16 (draft, April 2008)

In order to resist the inertia forces, various methods of cargo securing are applied in practice. These can be basically divided into tie-down lashing, direct lashing and form-fit blocking as well as combined cargo securing, Figure 2.

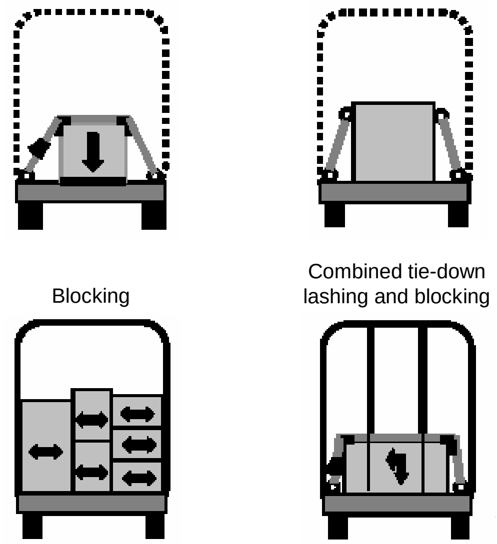


Figure 2. Basic types of securing cargo on road vehicles (Source: VDI 2700-16, draft, April 2008)

Tie-down lashing involves the tensioning of suitable lashing devices (usually straps) that tie down the cargo. The permanently acting tension forces which are necessary to secure the cargo, are conducted via the lashing devices into the so-called lashing points (usually loops/rings) and thus into the vehicle structure. Direct lashing involves only a slight pre-tensioning of the lashing devices (straps or chains). This method generates the temporary forces required to secure the cargo depending on the driving dynamic requirements directly from the inertia forces, reduced by the friction force only and generated as a consequence of the inertia force. Here too, the securing forces are conducted via the lashing points into the vehicle structure.

Securing the cargo by means of form-fit methods is achieved without tie-down lashing or direct lashing. The cargo, under the influence of the driving dynamic inertia forces, is directly supported by the vehicle superstructure or suitable additional devices.

Furthermore, cargo can be secured by using a combination of methods. In general the combined measures are tie-down lashing in conjunction with form-fitting.

CONTENTS OF ISO 27956

Scope

ISO 27956 applies to N_1 vehicles and N_2 vehicles up to 7.5 t in compliance with the ECE classification as per ECE/TRANS/WP.29/78/Rev.1/Amend.2 "Consolidated Resolution on the construction of vehicles (R.E.3)". For vehicles preliminary designed for goods transport and derived from a passenger car (M_1 vehicle), only the partitioning system requirements of ISO 27956 apply. Figure 2 gives a few examples of vehicles covered by ISO 27956. The characteristic feature of all these vehicles is that the superstructure consisting of occupant compartment and the loading space forms a closed unit (closed body or "one-box vehicle").

For these vehicles minimum requirements are defined for the devices intended to secure the cargo as well as associated test methods. The intention is to ensure that the cargo is secured in a roadworthy and operationally safe manner to protect the occupants against injuries caused by shifting cargo. This is the same intended objective as set out in DIN 75410-3. ISO 27956 additionally mentions as a clarification that extreme loads, such as those that may occur in frontal collisions, are not taken into account by this standard. For this the term "roadworthy" has been included. It means design concepts aiming at excluding harm (e.g. injuries, fatalities) to the occupants of a vehicle travelling on public roads under normal conditions of operation (including full braking, emergency braking, braking in a curve, fast lane changing and driving in a curve).

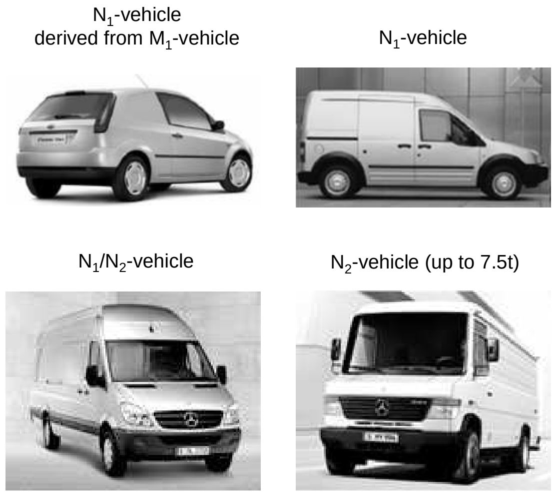


Figure 3. Examples of vehicles covered by ISO 27956

Requirements and Tests

In general N_1 vehicles and N_2 vehicles up to 7.5t must be fitted with suitable equipment to prevent the cargo from penetrating the occupant compartment. Therefore, protection devices consisting of a partitioning system and lashing points must be provided. Partitioning systems are defined as a device (e.g. bulkhead, partition wall, grid) which fully or partially separates the occupant compartment from the loading space. Lashing points are attachment parts on the vehicle or integrated devices (e.g. rings, eyelets, hooks, loops, oval members, hooking-up edges, threat connections, rails) to which lashing devices can be connected in a form-fit manner. They are designed to transfer the lashing forces to the vehicle structure.

Partitioning Systems

Dimensions

The partitioning system shall fully separate the occupant compartment from the loading space across its entire width and height. In addition ISO 27956 takes into account permissible exceptions which occur in practice. If the loading space extends above the occupant compartment, it may be limited in height to the horizontal separation between the occupant compartment and the upper part of the loading space. In the case of vehicles that are only equipped with a driver seat and have no passenger seat, the partitioning system does not need to cover the entire width of the vehicle. However, the protective zone behind the driver seat to be described below must be covered and the seating position of the driver must also be sufficiently protected against laterally shifting cargo. Figure 4 shows examples of partitioning systems in various vehicles.

Figure 4. Examples of partitioning systems

If there is a gap between the partitioning system and the vehicle body, it shall not be more than 40mm. It also states that such a distance must be observed without removing any existing covering (or trim). A greater distance is permissible if the vehicle has corrugations in the side walls (see Figure 5, top) and to ensure proper deployment of curtain airbags, if fitted.

If the partitioning system consists of a grid or cargo net, a rigid test device (e.g. an iron rod) with a front surface of 50mm x 10mm shall not be able to pass such nets or grids in any orientation. In order to verify this, the test device is passed in a horizontal direction parallel to the x-axis of the coordinate system of the vehicle and can at the same time be rotated about its x-axis in any orientation, Figure 6.

Testing

The test conditions described below involve loading exerted by two different test plungers (Type 1 and Type 2). The partitioning system shall not deform permanently by more than 300mm (see Figure 5, bottom). No sharp edges or other deformations during the process are permitted to appear which might result directly or indirectly in injuries to the occupants.

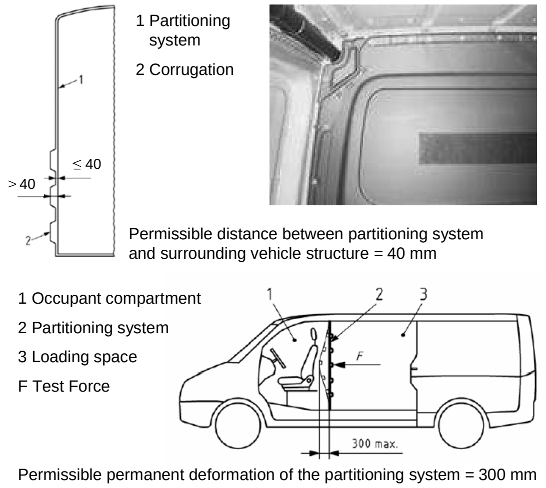


Figure 5. Partitioning system requirements regarding deformation under test loading with plungers (bottom) and the distance of the surrounding vehicle structure (top)

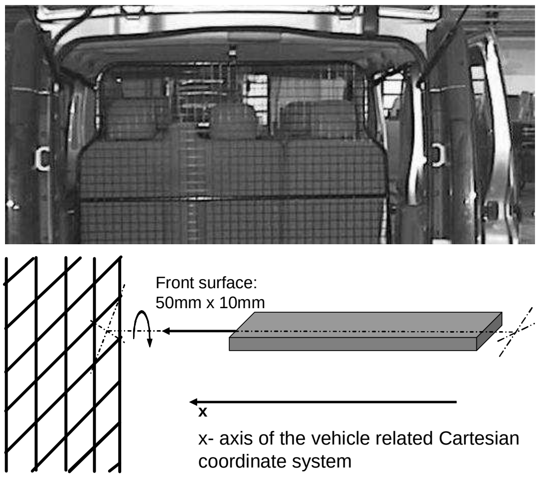
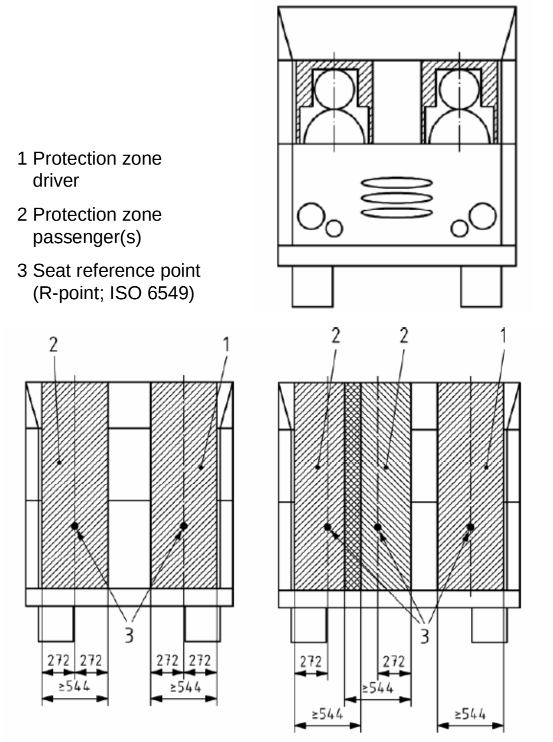


Figure 6. Testing the maximum permissible width of the gap of a partitioning system consisting of a grid or net using a rod test device

The partitioning system displays special protection zones behind the seating positions of driver and front passenger(s) or of the passengers sitting on the rear seats in dual cabins, if fitted. For this area more stringent requirements are stipulated to protect against penetrating cargo. These protection zones span the entire height of the occupant compartment and are 544mm wide each. Their vertical limits run symmetrically to the seat reference point (R-point, see ISO 6549) of the respective seat in a distance of 272mm, Figure 7. Behind a seat bench these protection zones may overlap between the R-points.



Example of a 2-seater occupant compartment

Example of a 3-seater occupant compartment

Figure 7. Protection zones of the partitioning systems behind driver and front passenger(s)

To test the strength of the entire partitioning system and its fixation, a large plunger piston (Type 1) has to be applied, see Figure 8, left. The test plunger piston has a flat square surface with a side length of 1,000mm and an edge radius of less than 20mm. It shall be applied with its central axis in the geometric centre of the partitioning system (based on its height and width).

The test force F (compressive force) has to be calculated on the basis of the mass m_P of the maximum payload of the vehicle in accordance with the equation

$$\mathbf{F = 0.5 \cdot m_P \cdot g}$$

(g = acceleration of gravity = 9.81 m/s^2).

This test force acts horizontally in the longitudinal direction (i.e. in x-direction of the vehicle-based coordinate system) on the partitioning system.

In vehicles in which the opening of the rear loading doors and/or the dimensions of the partitioning system, make the application of the Type 1 plunger piston impossible, a corresponding plunger piston of reduced dimensions and of the maximum possible rectangular geometry should be used, see Figure 8, right.

When testing the partitioning system, the test force F has to be applied as fast as possible within a maximum of 2 seconds and shall be maintained for 10 seconds. This is intended to simulate the loading of the entire partitioning system by the cargo during full braking.

Standard design

Design with reduced width

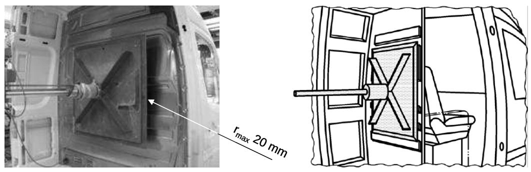


Figure 8. Plunger piston Type 1 (large plunger piston) to test the strength of the entire partitioning system and its fixation

Additionally, a second, smaller plunger piston (Type 2) is employed to test the strength of the partitioning system in the protection zones. This plunger piston has a flat square surface with a side length of 50mm and an edge radius of a maximum of 0.5mm.

This small plunger piston shall be used to apply force to any desired point of the retaining device only within the protection zones. If the partitioning system consists of a grid or net, the plunger piston (Type 2) shall be applied to the points were the bars crisscross. If a door or windows are located in the protection zone, such elements shall also withstand this test, Figure 10. The window material may fracture, as long as the deformation criteria given in the standard are met.

For the test using the smaller plunger piston (Type 2) the test force F shall also be applied horizontally in the longitudinal direction and calculated on the basis of the mass m_P. The equation to be applied here is

$$\mathbf{F = 0.3 \cdot m_P \cdot g}.$$

Nevertheless, this test force should not exceed 10 kN.

Identical to the large plunger piston (Type 1), the small plunger piston (Type 2) must generate the test force as fast as possible within the maximum

2 seconds and then be maintained for 10 seconds. This simulates a situation, for example, in which only a part of the cargo is directly in contact with the partitioning system which is directly loaded within the protection zone.

Figure 9. Plunger piston Type 2 (small plunger piston) to test the strength of the partitioning system within the protection zones

During the tests the partitioning system must either be installed in the specific vehicle or its body-in-white in order to ensure that the fixation corresponds to the original installation conditions. If the tests cannot be conducted this way, the partitioning system with its fixation elements shall be attached to a rigid frame with its attachment hardware.

The set-up of the rigid frame shall incorporate a horizontal surface which replicates the general level of the cargo space floor. The attachment points have to reproduce the geometry of the vehicle in which the partitioning system will be installed.

For both pistons (Type 1 and Type 2), the use of adapters between the partitioning system and the surface of the piston is permissible if necessary. This enables, for example, an even distribution of the contact pressure for offset partitions.

Lashing Points

<u>Number, Alignment and Dimensions</u>

For vehicles addressed in the scope of ISO 27956 lashing points are mandatory. They can be located in the floor and/or in the side walls of the loading space. Lashing points which comply with the requirements of the standard and which are located on the side walls have to be aligned as closely as possible to the loading space floor. Hereby a distance of 150mm to the loading space floor shall not be exceeded.

In practice, these days lashing points are also found in rails on the sidewalls which are located clearly higher up, Figure 11. These are additional lashing points which are not covered by the scope of ISO 27956. If necessary these additional lashing points could later on also be taken into account in a supplemental section of ISO 27956 as elements of an additional system installed in the vehicle for the securing of the cargo.

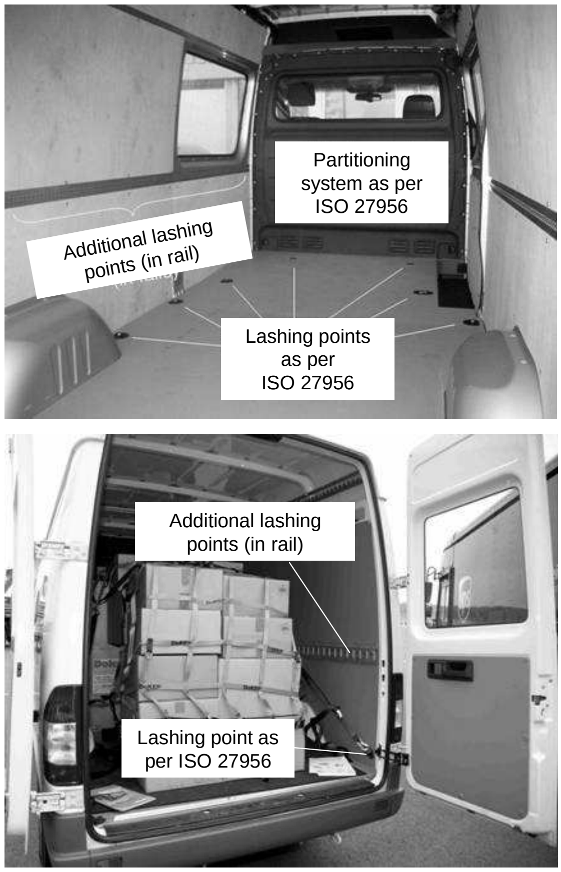


Figure 10. Load securing devices (partitioning system and lashing points) as per ISO 27956 as well as additional lashing points (in rails) in the sidewall of a closed-body N_1 vehicle

The design and the strength of lashing points in closed-body N_1 vehicles have frequently been the subject of intensive discussions both at a national level during the development and revision of DIN 75410-3 (see also [3]), and during the drafting of ISO 27956. This can be traced back, among other things, to the various variants of lashing points that were available on the market for many years (for examples see Figure 12) and to the wide range of experiences in using them in practice.

In contrast to heavy commercial vehicles on a ladder-type frame basis, the design of the relevant structure to attach lashing points on closed-body N_1 and N_2 vehicles with their self-supporting superstructure is usually less rigid and solid. In order to be able to fulfil requirements to transform kinetic energy into the deformation of the vehicle structure in accidents and crash tests, certain zones that can also be located in the loading-space area, have to deform in a predetermined manner under the influence of mechanical stresses and strains. This means that the anchorage of lashing points in closed-body N_1 and N_2 vehicles cannot be designed to have any degree of rigidity.

Figure 11. Examples of lashing point designs seen in practice for securing cargo in closed-body N_1 and N_2 vehicles

On the other hand, as far as the user is concerned, it is important that the lashing points are not overly permanently deformed when required load securing forces are applied using the available lashing devices. Otherwise, the consumer may thing twice about applying the forces required to properly secure the cargo so as to avoid damaging the lashing point anchorages in his vehicle.

This conflict of interests and the coordination of the interplay of lashing devices and lashing points were treated again in detail in the development of ISO 27956. It determined that still potential exists to harmonise the technical requirements and the design of the lashing devices, on the one hand, and the lashing points on the other hand. According to the ISO working group WG9, the various vehicles and easily comprehensible related information for the consumers should be considered more than before.

The geometric design of the lashing points is the responsibility of the vehicle manufacturer and is not stipulated in concrete terms in ISO 27956. The international standard contains drawings of some typical examples of designs of lashing points. Irrespective of the design of the lashing points chosen, a cylindrical probe shall be passed through the opening of the lashing point. New here is that according to ISO 27956 the diameter of this probe depends on the Gross Vehicle Mass of the vehicle, which has been divided into three classes for this purpose, Figure 13, top. The basic idea behind this was, firstly the function of the lashing point, for example to fit to a lashing device hook. Secondly, a standardised design of geometry and strength of such hooks could simplify the use of lashing devices that match the vehicle. Another requirement was that the inner diameter of a lashing point should not to be too small as in practice lashing straps are also passed through the lashing points without hooks (see Figure 12, bottom right). If the diameter of the lashing point was too small, this could lead to unfavourable folds in a strap.

d_1 [mm]	Gross Vehicle Mass [t]
35	$5.0 < m_{GVM} \leq 7,5$
25	$2.5 < m_{GVM} \leq 5.0$
20	$m_{GVM} \leq 2.5$

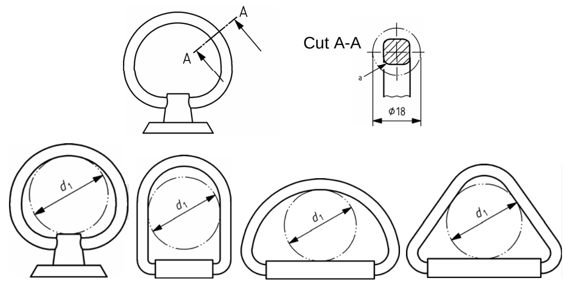


Figure 12. Examples of typical shapes of lashing points and dimensions stipulated by ISO 27956

Likewise considering the function of the lashing points in practice and, for example, the provision of suitable hooks, ISO 27956 stipulates that the maximum cross-section surface of the material of an eyelet or a ring shall not be larger than 18mm (see Figure 12). If the vehicle manufacturer designs the lashing point in a different shape or using different dimensions, he should provide adequate fastening elements to match the lashing devices. This also applies if the lashing points only consist of a thread connection.

Conforming to their use as a means to secure cargo (predominantly by tie-down lashing) it is also stipulated that lashing points should be arranged in pairs located opposite each other. The lashing points should be distributed as evenly as possible along the length of the vehicle and as close as possible to the sidewall.

The number of lashing point pairs and their alignment in the loading space depends on the maximum distance between the lashing points in the longitudinal direction of the vehicle and the length of the loading area. The distance l_S between two lashing points shall not be smaller than or equal to 700mm. This distance may be exceeded, but it must never exceed 1,200mm. In longitudinal direction the distance between the boundary of the usable loading space length and the lashing points on the front side or the rear side shall not be more than 250mm. The lateral distance to the usable loading space width and the lashing points shall be not more than 150mm. For vehicles with a loading-space length up to 1,300mm, at least two lashing point pairs shall be provided (two lashing points on each side).

As a rule the loading surface of a closed-body vehicle is not perfectly rectangular. Entry steps by the lateral sliding doors and the wheel arch protrudes generally more than 150mm into the side of the loading space. Figure 13 shows an example. Here, two lashing points have been offset inwards near the side door. They can be considered as an additional lashing point pair if the stipulated distance $l_S \leq 700$mm (or $l_S <$ 1,200mm) for the remaining lashing point pairs has been considered.

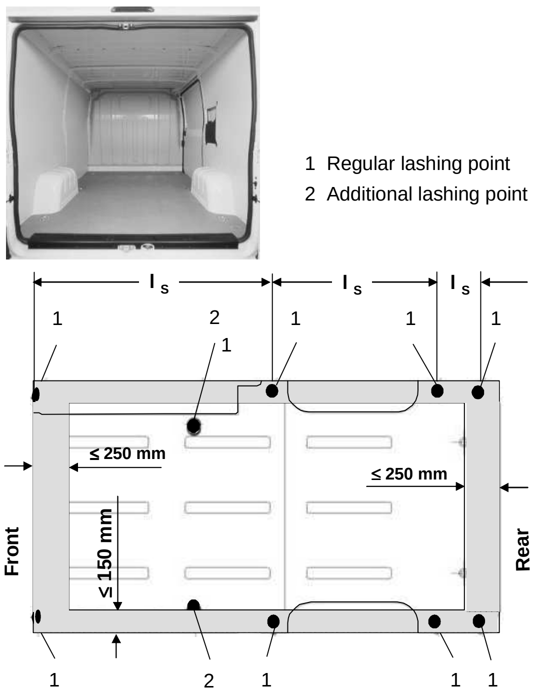


Figure 13. Example of the alignment of lashing points in a closed-body N_1 vehicle

The minimum number N of lashing point pairs to be installed is derived from the length L of the loading space (measured along the centre of the loading space floor where y = 0), taking into consideration the distances of 250mm at the front and rear side as well as a regular distance of the lashing point pairs of 800mm in accordance with the equation

$$\mathbf{N = 1 + (L\,[mm] - 2 \cdot 250\,mm) / 800\,mm.}$$

Applying the conventional mathematical rounding rules the result of the calculation for decimal places in the range .50 - .99 are rounded up and decimal places in the range .01 - .49 are rounded down. If, for example the length of the loading space L = 2,550mm, the minimum number N of required lashing point pairs is:
N = 1 + (2,550 mm – 2 · 250 mm) / 800 mm =
1 + 2.56 = 3.56 rounded up to N = 4 lashing point pairs.

Testing

In principle, the mechanical loading of the lashing points depends on the mass of the maximum permissible vehicle payload. This loading can, as extensive sample calculations have shown, vary considerably for different vehicles with the same permissible total mass. This is why equations were developed for ISO 27956 which can be employed to calculate the nominal tensile force of a lashing point based on the maximum vehicle payload. Larger vehicles generally have more lashing point pairs located in the loading space than small vehicles. This also applies with reference to the existing lashing point pairs facing the mass of the maximum vehicle payload. Accordingly, various factors were integrated into the formulae for the vehicles in question depending on their Gross Vehicle Mass m_{GVM}. To do this, the vehicles were classified into three groups ($2.5t \leq m_{GVM}$; $2.5t < m_{GVM} \leq 5.0t$; $m_{GVM} > 5.0t$). In addition, in order to avoid outliers in the calculation results, the resulting nominal tensile forces generated by the formulae were restricted to an upper and a lower limit.

Table 1. shows an overview of the equation for calculating the nominal tensile forces of lashing points in accordance with ISO 27956. The vehicle classes selected here based on the permissible total mass are the same as those stipulated for the test probe for the inner diameter of the lashing points (see Figure 12). It has to be expected that the vehicle manufacturers will in practice base their lashing point configuration of their various model ranges lashing points on the upper limits (F_N = 8.0 kN, F_N = 5.0 kN, F_N = 4.0 kN). If this proves to be the case, the manufacturers of lashing devices could provide

products correspondingly divided into three classes with matching hooks and nominal tensile forces to secure cargo in vehicles with a Gross Vehicle Mass up to 2.5t, over 2.5t to 5.0t and over 5.0t to 7.5t.

According to ISO 27956 every lashing point in a specific vehicle is to be capable of resisting loading in accordance with the formula and details set out above under any angle spanning 0 to 60° in the vertical, Figure 14.

Table 1. Calculation of the nominal tensile forces per lashing point as per ISO 27956

Nominal tension force F_N [kN]	**Gross Vehicle Mass m_{GVM} [t]**
$F_N = \frac{1}{4} m_P \cdot g$ but $3{,}5 < F_N \leq 8{,}0$	$5 < m_{GVM} \leq 7{,}5$
$F_N = \frac{1}{3} m_P \cdot g$ but $3{,}5 < F_N \leq 5{,}0$	$2{,}5 < m_{GVM} \leq 5{,}0$
$F_N = \frac{1}{2} m_P \cdot g$ but $3{,}0 < F_N \leq 4{,}0$	$m_{GVM} \leq 2{,}5$
m_P is the maximum payload in kg g is the acceleration of gravity (9.81 m/s^2)	

1 Floor of the loading space
2 Lashing point under test
3 Reference point and direction of measuring of the maximal lasting deformation
F_N Nominal tension force

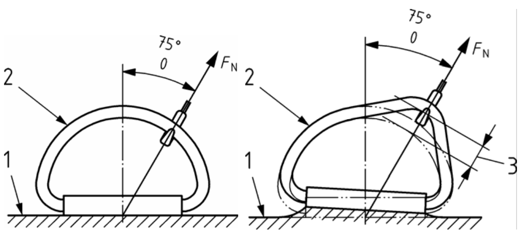


Figure 14. Testing the strength of a lashing point

<u>New Test Procedure</u>

The only decisive criteria for the testing of the strength of a lashing point are safety and functionality for cargo securing. These criteria have to be ensured under normal operating conditions and under a specific loading. The normal operational loadings are derived from the cargo securing requirements.
For example, if the cargo is secured by tie-down lashing, the (known) nominal tensile force F_N of the lashing points limits the maximum pre-tension force to be applied. If this possible pre-tension force does not suffice to completely secure the cargo in a present case, the cargo must be secured by a combination of methods. As a rule this involves the additional supporting or blocking of the cargo by form-fit methods.

It can be assumed that according to what has now been many years of practical experience, the nominal tensile forces of the lashing points for securing the cargo defined in DIN 75410-3 or the equivalent in ISO 27956 are sufficient. For newer vehicles, problems with lashing points being completely torn away are hardly heard of. Nevertheless, there have been repeated reports of "visible" deformations of lashing points. If such deformations are purely elastic, they return to their original shape once the loading on the lashing point has been removed and therefore are completely harmless. Plastic deformations that persist after the loading on the lashing point has been removed are a problem, however.

During the initial loading of a lashing point up to the nominal tensile force F_N and beyond up to a defined excess loading, such plastic deformations must be tolerated for design reasons of some lashing points in vans. The decisive criterion is thus the extent of the plastic deformation of the lashing point under this loading. Also, in the case of further loading the lashing point shall not indicate additional excessive plastic deformation.

In light of this the ISO workgroup WG9 has developed a new procedure to test lashing points which is intended both to provide reproducible as well as unambiguous measuring results of the relevant deformations. Regarding the reproducibility of the results, it is favourable that the relevant deformation and force measurements begin under a specific pre-load followed by a permanent loading.

The test is divided up into four steps:

Step 1

- Apply a pre-load of 5% of the nominal tension force F_N;
- Set the deformation measurement system to zero.

Step 2

- Increase the load within 20s up to F_N;
- Hold the load for at least 30s;
- Release the load to zero;
- Reload the system up to the pre-load;
- Measure the permanent deformation of the lashing point (including the vehicle structure) at the point of force application in direction of the force application – test passed if permanent deformation is ≤ 12mm.

Step 3

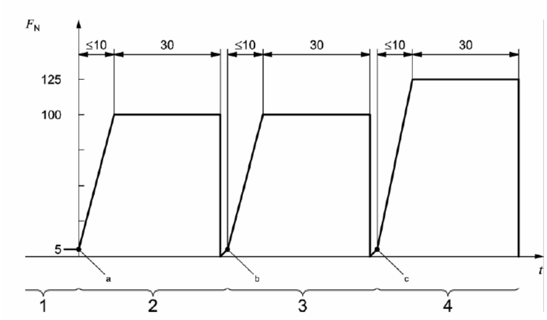
- Apply again within 20s a load equivalent to F_N;
- Hold the load for at least 30s;
- Release the load to zero;
- Reload the system up to the pre-load;
- Measure the permanent deformation – test passed if the limit specified in the 2nd step is not exceeded.

Step 4

- Increase the load within 25s up to a force of 1,25 × F_N;
- Hold the load for at least 30s;
- Release the load to zero;
- Test passed if the function of the lashing point remains intact; additional permanent deformation permissible.

The relevant parameters of this test procedure are shown in Figure 15. A body structure representing the vehicle shall be used for the test. Any reaction forces, if induced into the vehicle structure by the test equipment, should be applied within a distance of at least 300mm to the lashing point under test. However, this distance shall not be less than 100 mm.

Any lashing point on the vehicle may be selected for testing. The lashing point has to be loaded with a suitable lashing device. Adapters may be used if this requires the even distribution of test force into the lashing point. ISO 27956 does not prescribe the hardware for the testing of the lashing points. The strength of the lashing points can also be evidenced by a calculation. In this case, the vehicle manufacturer must demonstrate in a comprehensible manner the equivalence of the calculation to an actual test as per ISO 27956.



1 **Step 1:** **a** **set deformation to zero**
2 **Step 2:** **b** **1st deformation measurement**
3 **Step3:** **c** **2nd deformation measurement**
4 **Step 4**
F_N **Nominal tension force [%]**
t **Time [s]**

Figure 15. Parameters of the four-step procedure to test the strength of the lashing point

<u>Consumer Information</u>

In order to ensure a correct and proper use of the lashing points installed in the vehicle when carrying out cargo securing measures, ISO 27956 stipulates that the maximum lashing point strength shall be provided in the vehicle owner's manual. In addition, a corresponding label has to be attached inside the cargo compartment of the vehicle, Figure 16. This label shall be inscribed with white letters on a blue background with a white border. The label should be fixed in the loading space in a clearly visible position, which normally is not covered by the cargo, e.g. in the upper area of the partitioning system near the door. The minimum size of the label is 100mm x 130mm.

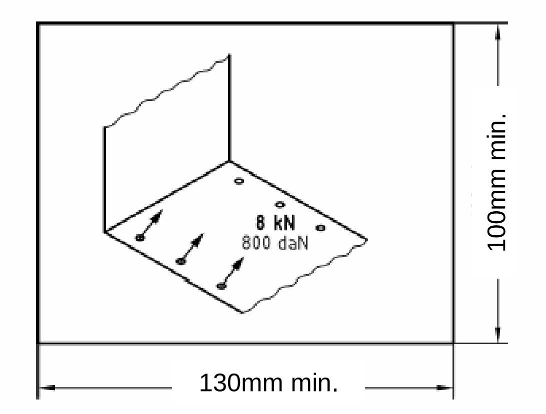


Figure 16. Example of labelling of lashing points

EXPERIENCE GATHERED SO FAR AND PROSPECTS OF FURTHER DEVELOPMENT

The first draft (Committee Draft) ISO/CD 27956 was published in November 2007 and with an international committee balloting it was successfully completed in January 2008. After some fine-tuning considering the comments received, the second draft (Draft International Standard) ISO/DIS 27956 was published in April 2008 for the second international ballot which was passed again without any negative votes until September 2008. Having apprised and incorporated the comments received, the working group ISO/TC22/SC12/WG9 finalised the Standard ISO 27956 for publication in spring 2009.

One focus of the informal discussions and the exchange of experience is the execution of lashing point tests according to the new multistage test procedure (step 1 to step 4). The first results show that as far as the deformation of the lashing points is concerned, the force directly upwards (angle between vertical and the tensile force 0°) can often be seen as a “worst case” scenario. In individual cases, however, this can depend on the design of the lashing point and the vehicle structure underneath.

First individual tests of lashing points involving a vehicle from a current model range have been conducted. The permanent deformations recorded in step 3 of the test (under 5% nominal tensile force) was in one case around a maximum value of 8mm. With a view to ensuring a general buffer for the statistical spread of the production the final decision of the Working Group was to set the corresponding maximum value in the standard to 12mm.

How the vehicle manufacturer, the supplier and the testing institutes estimate the potential for optimisation of individual, possibly “critical” lashing points, could play a decisive role for a discussion in the near future. This possible further discussion of the maximum value of 12mm will depend on more findings of manifold practical tests following the new 4-step-procedure stipulated now in ISO 27956. There is a broad consensus, that this new test procedure is able to deliver reproducible and precise results.

The original remit of ISO/TC22/SC12/WG9 included the conversion of the national standard DIN 75410-3 into the international standard ISO 27956. In the future, there could be a requirement for the standardisation of further assemblies for securing cargo in closed-body delivery vans. This would be equipment required for form-fitting securing of cargo and for locking (blocking) of cargo via appropriate ratchets and bars, Figure 17. Complete shelf and fitted cupboard systems are also available.

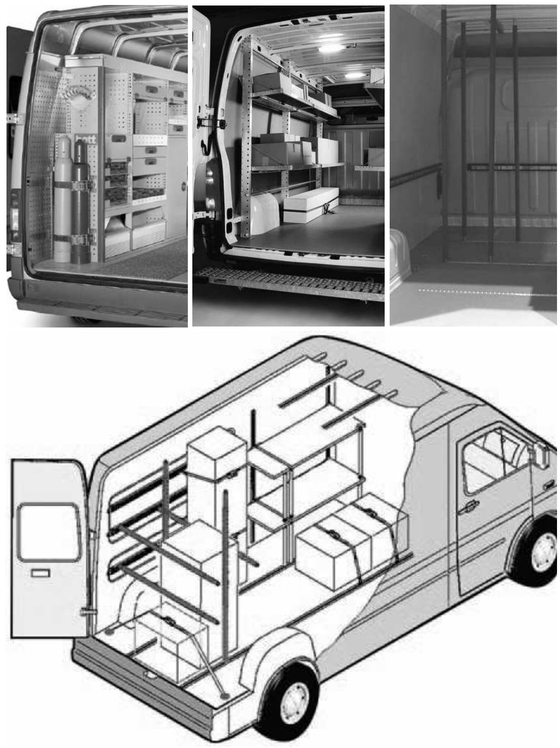


Figure 17. Additional vehicle installations for the securing of cargo in vans

These systems have already been tested in accordance with so called “in-house defined” test procedures taking into account the known relevant load cases. However, a complete harmonised transferability in all cases is not possible or sensible. Freely defined test requirements and associated standard test procedures can demonstrate and ensure the performance of the systems. But in the light of the globalised market place there is an increasing need for a suitable international standard, for example in an extended standard ISO 27956.

Please note: *This paper describes the contents of cited standards, in particular ISO 27956. This article does not hereby replace these standards. Only the cited standards in their original and respective current version have valid and binding force.*

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