BEYOND NCAP: PROMOTING NEW ADVANCEMENTS IN SAFETY

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ABSTRACT

Over the last decade Euro NCAP has become recognised as a reliable indicator of independent consumer information with an acknowledged positive effect on car safety. Most car manufacturers see the positive advantages of ensuring their vehicles achieve the highest possible result in this consumer test program. For Euro NCAP to keep its relevance it is important that the program reflects the improvements made in car safety over time.

Many of today's technological advancements are in active safety, driver assistance or in the combination of primary secondary and tertiary safety. Many of these safety functions are so new that no clear-cut procedures exist to test and rate them. Given this challenge, a system that enables carmakers to receive added recognition for important innovations beyond the star rating could promote the development of superior safety improvements and accelerate the introduction of new technology. Rewarding safety innovations will also keep the carmakers' commitment to Euro NCAP and help improve vehicle safety for the whole community.

The "Euro NCAP Advanced" reward is an addition to today's star rating. With the support of the automotive industry, Euro NCAP has developed a methodology, referred to as "Beyond NCAP", to allow the potential safety benefits of any new safety function to be determined. This process is based entirely on the assessment of scientific evidence presented in a dossier by the car manufacturer. An independent panel of experts reviews the extent of a safety issue which a new safety system aims to address. Through a logical and rigorous analysis of the way in which the technology has been developed, tested and validated, and from any real-world experience that may exist, the system's performance and its expected effectiveness can be estimated and eventually rewarded.

In particular, any submission needs to provide reliable evidence of the tests conducted and any assumptions made in assigning possible benefits for the new safety function. The method used for making these assessments also needs to be scrutinized. The challenge is to understand with an acceptable level of confidence how reliable the data presented is without intimate knowledge and involvement in the development of the technology. This is addressed firstly by selecting independent experts which are able to make judgments about the level of scientific proof provided and whether the benefits claimed are realistic and achievable. Secondly, the credibility of the source of the data is an important indicator of the reliability of the findings. Thirdly, publication in the scientific

literature increases the reliability of the findings, although this may not always be possible at the time of submission for reasons of commercial confidentiality.

The recognition of the potential benefit of these new safety technologies in no way undermines the importance of basic safety assessment expressed by the star rating. For this it is important that Euro NCAP continues to assess vehicle safety using existing test procedures and criteria. It is expected that the Beyond NCAP process will help identify the best assessment methods for upcoming technology. Euro NCAP intends to implement these methods for an improved rating of car safety in the future.

INTRODUCTION

Euro NCAP has been markedly successful in helping to improve the crashworthiness of today's passenger vehicles around the world. Despite increasingly challenging requirements put in place since 2009 [1] many of today's passenger cars achieve a 5-Star overall rating. A recent comparison between Euro NCAP test results and real-world crash data [2] showed significant differences in injury risk between 2- and 5-star Adult Occupant Protection rated cars in Euro NCAP for risk of fatality, confirming that car manufacturers have focused their safety performance on serious crash outcomes.

The change in attitude by manufacturers towards Euro NCAP and the fact that their performance in Euro NCAP tests is frequently used as part of their marketing strategies is further evidence that Euro NCAP tests are taken seriously and deemed relevant. Over the years, interest by consumers across Europe has also grown, indicated by the increasing number of visitors on the Euro NCAP website from across the European Union and beyond. Recently, some European countries have started to use star ratings to provide tax incentives for purchase and use of safe cars or have incorporated a minimum star rating in their fleet buying policy.

Auto manufacturers' critical response to Euro NCAP has moderated considerably since it was introduced. Today, most of them see the positive advantage of ensuring their vehicles achieve high performance in a NCAP test. It is vital that this continues to ensure Euro NCAP's relevance in tomorrow's safety arena.

It is clear that Euro NCAP has been successful for a number of reasons. First, the community has grown to accept star ratings, which are easy and accessible, as a legitimate test of safety performance. As safety is now clearly a marketing tool by many manufacturers, it has created competition between many of them in offering the "safest" vehicle on the market. Indeed, many of today's manufacturers see safety as a core part of their brand image, which they would not like to lose.

Because of this success, however, Euro NCAP is in serious danger of becoming obsolete unless it continues to lead this activity. With the advent of rapid technological advancement in both active and passive safety, it is especially necessary to ensure Euro NCAP's assessment is further developed to take account of the safety benefits of new technologies. Knowledge about safety among manufacturers and component suppliers has grown noticeably over the last decade or two, in part, because of the efforts of bodies such as Euro NCAP. Many manufacturers are active in conducting their own safety research but while it would be expected that new innovative safety improvements would lead to increased scores in Euro NCAP ratings, this does not necessarily follow. Many of today's safety improvements are in active safety and many of these features are not taken into account (and do not fit) with the Euro NCAP's current predominately crashworthiness test approach. Moreover, a number of manufacturers exceed today's test criteria for which they receive little added benefit. It is clear that many of today's new vehicles offer safety levels well above those prescribed by government regulations; that is, best practice today exceeds prescribed mandatory levels of safety.

A system therefore that would enable auto manufacturers to receive a recognised reward for safety enhancements would seem to be a positive step forward in both developing superior safety improvements and the introduction of new safety technology. This would also act to increase their commitment to Euro NCAP in the years ahead and to work towards helping improve vehicle safety for the whole community of consumers in the coming years.

While Euro NCAP's work continues to re-examine the suitability, relevance and comprehensiveness of today's tests and threshold values as described in the Roadmap [3], this paper focuses on how the safety organisation is addressing the rapid introduction of new safety technologies, especially those aimed at preventing and mitigating crashes, and supporting the driver or rescue services.

THE PRINCIPLES OF BEYOND NCAP

Euro NCAP crashworthiness tests are based primarily on government regulation tests and injury criteria. In a number of cases, these test criteria are made more stringent to ensure a higher level of safety ensues. The tests are developed by international research organisations with industry and are accepted because of their high scientific validity. It is vital that any expansion of Euro NCAP activities is based on robust scientific procedures and best practices which are open and transparent. This is critical for ensuring that Euro NCAP maintains its credibility among automotive and parts manufacturers as well as the community in general. It should also be transparent and subject to rigorous assessment to maintain Euro NCAP's leading role in this area.

For it to be appealing and meaningful, the new reward system must have the capability of assigning added benefits to new and innovative initiatives and technologies that are rapidly being developed by manufacturers in their quest to build safer vehicles that are not currently encouraged. Moreover, it must also be capable of fast progress to keep up in this dynamic environment. It is also important that any new development in Euro NCAP be sensitive to any potential misuse. Further, the process should act to encourage manufacturers to apply highest test standards to the safety system to ensure current safety improvement levels will continue.

Hence, the proposed "Beyond NCAP" methodology is an addition to today's assessment (star rating) process. It has the capability of assigning additional reward for any new safety technology introduced by a manufacturer where significant safety benefits can be demonstrated scientifically. Unlike normal NCAP testing, this process is based entirely on the assessment of scientific evidence presented by the car manufacturer. Timing is critical to be sure to keep up with safety advancements. Of course, Euro NCAP continues to assess vehicle safety using existing test procedures and criteria and to work towards reviewing these procedures and criteria as new evidence becomes available.

Safety Issue and Expected Benefit

Road safety has benefited greatly from adopting a scientific approach to problem resolution since the 1960s and 1970s. William Haddon proposed the "Haddon Matrix" as a systematic way of examining road safety problems and issues [4]. More recently, the process of "identification, investigation, implementation and evaluation" have become commonplace in the conduct of successful scientific studies.

In road safety, the first step in the process is identifying significant safety areas and the mechanisms of accidents and/or injuries that govern the problem. Historically governments and research organisations have used the traditional statistical approach. Moreover the manufacturers are playing an increasing role these days using their own in-depth crash data and/or data collected on their behalf, which normally allows a more detailed level of analysis.

Solutions often follow the identification of accident problems and causes. As with many scientific studies, the challenge often comes down to having reliable and plausible evidence available for analysis. In other words: How do you judge what the potential safety benefit is likely to be for any new safety advancement and what reward does one assign to this innovative measure? Assigning safety benefits without real world evidence of crash or injury savings is often fraught with difficulty. Nevertheless, governments and manufacturers are expected to make these assessments regularly when considering the introduction of new safety countermeasures. In passive safety, the most common method is to conduct a series of crash tests and convert the results into injury mitigations via injury assessment functions. Hence the assessment of the likely harm (deaths, injuries, and property damage) saved can be an effective means of expressing the safety benefit ahead of real world experience.

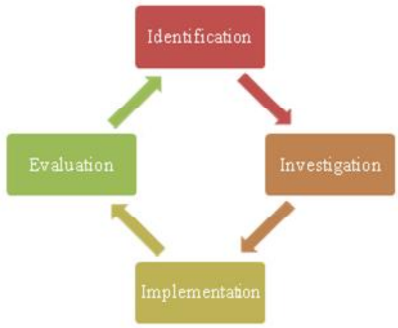

Figure 1 Scientific approach underlying the Beyond NCAP methodology.

While it is recognised that for active safety innovations the proposed safety benefit might be more complex to evaluate before introduction, the estimate of the expected real-world benefit based on a closed-loop "identification, investigation, implementation and evaluation" process is paramount to the "Beyond NCAP" methodology.

Assessment Procedures

A key chain in linking the safety issue with the expected benefit for a certain technology is the test procedure designed to verify the system's intended performance. Reliable evidence of the tests conducted, simulations run and any assumptions made in assigning safety benefits for the new technology need to be provided. The method used for making these assessments would also be required in order to evaluate its credibility. For Euro NCAP to know with an acceptable level of certainty how reliable these savings data are without intimate knowledge and involvement in the conduct of the study, the following is ensured:

Independent assessments Independent evaluators, typically experts in the area of interest are used to review the data provided. If conducted properly, peer-review processes can highlight strengths and limitations in the processes followed during the analysis. Experts are able generally to make judgements about the level of scientific proof provided and whether the benefits claimed are realistic and achievable.

Best practice Best practice can be another means of assessing scientifically the potential safety improvement of new advancements. Methods applied that follow a best practice approach recognised by the scientific community may increase the levels of confidence that can be put on the data provided.

Data sources, references and citations The credibility of the source of these data is also an important indicator of the reliability of the findings. Independent test houses with an established reputation would generally be more likely to provide unbiased assessments of benefits than those with a vested interest in the results. Publication in the scientific literature is a good indicator of the reliability of the findings, although this may not always be possible at the time of submission for reasons of commercial confidentiality.

Witnessed demonstration In case of doubt in the test results and/or injury reductions claimed after a peer-review, or to enhance the information provided in the dossier, the manufacturer may be asked to demonstrate the system's functionality on the vehicle in the presence of one or more independent assessors.

The likelihood of potential harmful side effects is always difficult to judge from test data alone. Conducting a randomised control trial is often difficult to organise prior to the introduction of new safety technology, hence the need for ongoing monitoring of the real world experience using crash, performance data and/or user feedback. Without such analyses, it is impossible to judge whether the expected benefits from the technology have been, or are likely to be, realised.

PROTOCOL

Between the years 2006 and 2009 Euro NCAP members and industry representatives have developed a protocol documenting the "Beyond NCAP" assessment method [5]. The result is a procedure on how to verify and assess any new safety systems currently not already included in the rating scheme. The complete process is based on the notion that the manufacturer provides documentation (the "dossier") in a predefined and logical order, and that Euro NCAP will verify this documentation with regards to completeness, validity and reliability. The verification will be performed by an independent panel of experts, referred to as the Assessment Group, in two stages, involving the manufacturer in the consensus discussions at the end of each stage. Sensitive parts of the dossier can be made confidential at the manufacturer's request. If a robust case has been made by the manufacturer, the verification process will result in the decision to reward the manufacturer for the technology available on the vehicle at hand. This so-called "Euro NCAP Advanced" reward is limited to cars tested by Euro NCAP achieving at least three stars in the overall rating scheme (or in adult protection for cars tested before 2009).

Manufacturers can apply to Euro NCAP for safety systems that address all safety areas (primary and/or secondary and/or tertiary) except for those that are covered by existing Euro NCAP protocols. The Euro NCAP Advanced reward applies to the model on which it is fitted. However, it can be applied to other models with the technology provided sufficient additional information is shared on the safety system's functionality on the other models.

In the procedure the following steps are identified:

- Innovation;
- Safety Issue;
- Accident Mechanism / Injury Causation;
- Target Requirement;
- Test Procedures;
- Expected Benefit;
- Real World Evaluation / Experience

Figure 2 shows the relation between the different steps resulting in the assessment.

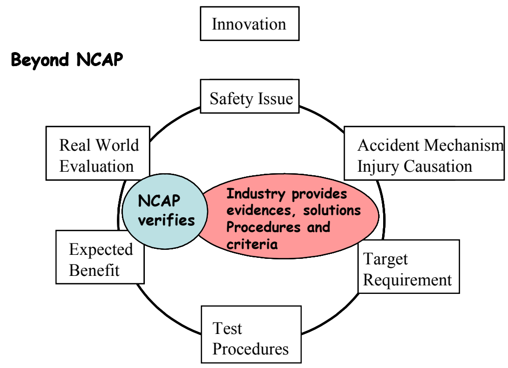

Figure 2. The Beyond NCAP assessment method

In the sections below each process for the assessment is described.

Innovation This first part of the dossier includes a technical description of the components and the functionality of the system. Based on the information provided to Euro NCAP, the dossier will identify if:

- the system is addressing primary and/or secondary and/or tertiary safety;
- a system with similar functionality has been assessed before;
- the system can be assessed with regular procedures (and hence whether it is already

covered by the star rating) or if a new procedure is required.

Safety Issue The next step in the process is to identify the relevance of the safety issue that the safety system aims to address. At this stage, the effectiveness of the safety system and any possible side effects are not considered. The key aspect is identifying the problem at large and the potential size of the safety benefit that the innovation does address in the context of entire Europe (EU-27 countries).

Based on the system's specification given in the first part, the field of application of the safety system has to be defined. This information is then judged by Euro NCAP on the:

- reliability of the methods;
- validity of the used data sources.

If the methods used are reliable and the data sources used are representative, then this will result in an agreement on the potential size of the safety benefit for the specific technology presented.

Note that the information provided here is most likely based on accident data, European or even transferred data could be used, indicating the number of accidents with, for example, severe injuries relevant to the safety system being assessed.

Accident mechanism / Injury causation After defining the type of innovation and identifying how many fatalities or injuries can potentially be saved by the system, the injury mechanisms/crash mechanisms causing the problem to be addressed by the innovation are defined.

Detailed understanding of the accident mechanism and/or injury causation is needed to ensure a correct definition of the target requirement and technical assessment (investigation of the correct phenomena) in a later stage. This investigation will identify:

- the accident mechanism and/or injury mechanism;
- the driver behaviour (if applicable, for instance for ADAS systems);
- the injury risk or transfer functions identifying the main accident parameters governing the system's effectiveness;
- the reliability and the validity of the data;
- the methods and the tools proposed.

This review should result in a deeper understanding of what key parameters are contributing to the accidents and their outcomes and which of these parameters will be used or have to be controlled by the system to deliver the benefit.

Target requirement The target requirements are the requirements set by the manufacturer on the important system parameters, identified in the last section. These form the basis for the criteria used in the test(s) proposed for the system. The target requirement needs to be defined in such a way that it is possible to know what the "innovation" is theoretically expected to do (e.g. keeping a car in the desired lane by a set lateral distance for lane keeping systems, or to keep the load on an occupant's chest below a certain threshold for an airbag).

The output from this part of the procedure is the:

- definition of the target requirement(s) in relation to methods and tools;
- understanding of the relationship between criteria and the system's benefit.

Test procedure This part of the dossier presents the methods by which the manufacturer has verified that the system works in the intended situations and in the designed manner. Evidence is requested that the system meets the manufacturer's own targets, and/or to estimate the technical efficiency on the basis of test series carried out. The test methods and target requirement(s) used to assess the performance of the innovation are reviewed considering the:

- methods and tools used;
- source and independence of data;
- reliability and validity of the results;
- criteria used;
- assessment procedure and results.

The test methods and criteria range from methods used in regulation or Euro NCAP to methods used by the industry internally. Also depending on the innovation and the target requirements, the testing can be performed experimentally, by computer simulation or a combination of both.
For ADAS systems in particular, driver simulator studies are relevant to quantify the effectiveness of the Human Machine Interface. The results will be input for the expected benefit discussions.

Expected benefit Having documented the actual performance of the system in relevant test conditions, and understanding the link between meeting the targets and the potential benefit of the system, the expected benefit of the innovation can be calculated. In the assessment process the following is considered:

- available methods / accepted methods;
- accident data used;
- inclusion of any side effects (e.g. driver adaptation);
- potential level of dissemination (for information only);
- market share (for information only);
- expected benefit evaluation.

Although the expected benefit is derived at the vehicle level (i.e the benefit assuming all cars were equipped with the technology), information is also requested on the potential level of dissemination of the system (is it standard on all variants, is it an option that is available on some variants) and the expected market share (expected number of sold vehicles per year). Note that both the potential level of dissemination and the expected market share are only for information and will not affect the expected benefit (at the vehicle level). However these numbers can be taken as an indication of the manufacturer's confidence in the system.

Real world evaluation / experience The real world evaluation is the final step in the dossier. Only by following up in the real world, can the true effect of safety developments be verified. The effect in real life may be different from the expected benefits in many ways. For instance, the accident or driving scenarios may differ, and drivers from a wide range of backgrounds may use the system in an unpredicted way. Generally, information learned from the follow up exercise can be used as input for the next development loop.

In the Beyond NCAP evaluation approach, the real world follow up is part of the case built by industry. The quality and credibility of the follow up can potentially influence the credit Euro NCAP gives to the innovation under study.

The most suitable method for real world evaluation is the *a posteriori* analysis using representative and detailed accident data. However, such studies are found to be complicated and very time consuming, in particular for avoidance systems. As such, there is an inherent conflict between a good quality real world evaluation process and the need for rapid answers. For systems only recently introduced or not yet available, no data may be available to perform a meaningful real world evaluation study. Especially for these systems, results from fleet studies with a limited number of vehicles and a limited number of drivers, feedback from consumers or even simulation studies can provide some indication of the real world benefit.

Generally speaking, systems with big effects are straightforward to verify, but systems with limited safety benefits are more complicated and time consuming to evaluate. For some systems, long term follow-up is necessary to understand behavioural adaptation.

FIRST RESULTS

Starting from 2010, the Beyond NCAP assessment method has been added to the Euro NCAP car safety program. Several manufacturers have been handed the Euro NCAP Advanced reward to complement the overall star rating achieved for a car model tested previously.

Successful applications represented a wide variety of safety systems recently introduced on the European market, including autonomous braking technologies (Honda CMBS), Lane Departure prevention and lateral assist (Opel Eye, Infinity LDP, VW Lane Assist, Audi Side Assist), pre-crash safety systems (Daimler Pre-Safe / Brake) and eCall systems (BMW Advanced eCall and PSA). In the development of the dossiers, extensive use was made of GIDAS (D) data, where possible supplemented with CCIS (UK), LAB (F) or non-European data. Most manufacturers were forced to make broad assumptions regarding the potential safety benefit for EU-27 due to a clear lack of statistics. This part has proven particularly challenging for those technologies that rely on the road or telecommunication infrastructure (e.g lane markings, GSM coverage).

Where the role of the driver is key in effectiveness of the system (e.g. warning based ADAS), a few manufacturers have referenced driver simulator studies and fleet operational trials, most outside the European Union. Surprisingly, very limited data was been offered regarding real world experience, even for systems that were on the market for longer periods outside of Europe.

DISCUSSION

The Beyond NCAP methodology proposes a new and unconventional way of assessing vehicle safety functions. The process presented here brings about positive aspects but also has its inherent risks. As the system was developed collaboratively between the auto industry, governments and consumer groups, the manufacturers have been committed to the new system from the start. The well structured approach facilitates an open platform of technical dialog between manufacturer and Euro NCAP's stakeholders whereby the manufacturer's in-depth knowledge about the system can be explored and design choices challenged. It will, it is hoped, lead to the identification of acceptable test and review processes as well as addressing issues associated with commercial confidentiality and additional research needs.
On the downside, the system is based entirely on evidence provided by car manufacturers and can easily be perceived as industry biased if not well understood. The process with its strong emphasis on safety benefit is held back by the relatively poor availability of high quality accident data across the European Union and the low market penetration of advanced safety systems on the European market to date.

The Euro NCAP Advanced reward system is open to different technologies but at this stage is unable to discriminate between comparable technologies based on real world effectiveness. A stronger feedback mechanism on real-life performance of systems assessed, involving industry and Euro NCAP, could provide a stronger basis for comparison. Hence, with increasing availability on the market, it is expected that knowledge will come available that would allow Euro NCAP to rate systems, for which the test procedures would be placed in one of the existing rating boxes [1].

CONCLUSIONS

Euro NCAP and car manufacturers jointly developed the Beyond NCAP methodology which allows the potential safety benefits of any new technology to be determined. The assessment is based entirely on scientific evidence and data presented by the vehicle manufacturer. A panel of independent experts looks at the extent of the safety problem which a new technology aims to address. Through a logical and rigorous analysis of the way in which the technology has been developed, tested and validated, and from any real-world experience that may exist, the system's performance and its expected effectiveness can be determined. Over the last year, already 13 systems have been assessed in this way, 11 of which were successful and were rewarded under the Euro NCAP Advanced banner. By rewarding technologies, Euro NCAP hopes to provide an incentive to manufacturers to accelerate the standard fitment of important safety equipment across their model ranges and helps the car buyer making a better informed purchase decision.

The consequence of the Beyond NCAP method described in this paper is that the car industry is given credit for new safety technology and improvements, on a "scientific" basis. The basic work to develop the evidence will be the role of industry, which in turn will make rewarded technology relevant in improving real world safety. When this becomes a natural process, it will also produce an implicit barrier to innovations that are not effective. The method itself will be reviewed and fine tuned from time to time in collaboration with the auto industry.

The recognition of the potential benefit of these new safety technologies in no way undermines the importance of basic safety assessment expressed by the star rating. For this it is important that Euro NCAP continues to assess vehicle safety using existing test procedures and criteria. It is expected that already by 2013 some technologies recently awarded will be included in the overall star rating [3].

Finally, the consumers play an important role in the quest for better safety and it is vital that they are kept informed about what is a desirable as well as an undesirable new technology. Beyond NCAP and the Euro NCAP Advanced rewards offer a mechanism for further advancing knowledge on safety technology in cars among the end users, the importance of which cannot be overstated.

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INSTALLATION PATTERNS FOR EMERGING INJURY MITIGATION TECHNOLOGIES, 1998 THROUGH 2010

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ABSTRACT

The period 1998 through 2010 has been one of great flux in the development and application of motor vehicle injury mitigation (safety) technologies. Over this period, vehicle manufacturers have implemented: depowered air bags, advanced technology air bags, side impact air bags, automatic occupant classification and air bag suppression, electronic stability control, daytime running lamps, advanced belt restraints, various driver warning and assist devices, automatic collision notification, etc. Most of these technologies have been led by manufacturers' voluntary development and application of emerging technologies. Some technologies have been driven by new rules, and some were permitted by rule changes.

The introduction and application of 28 safety technologies have been compiled in a database created by combining data from NHTSA and Ward's Automotive. A census of technology presence has been tabulated by: technology, model year, manufacturer, make, model, body style, and technology not available or technology presence as standard or optional equipment. The research includes information for specific identifiable technologies but does not include safety technology advances that manufacturers may have applied at an architectural or structure level in vehicle integration over this time period. Data is tabulated for each technology/model year pairing, analyzed as the proportion of vehicle models equipped with the technology, and tracked over time. Thus, researchers can determine which specific models are offered for sale with an emerging technology and the proportion of new models in each model year that are offered with the equipment.

Examination of the resultant data shows: 1) each new safety technology begins with small model penetration proportions, 2) the proportion of new vehicle models offered with an emerging technology grows over time, 3) commonly in about 5 years after first introduction the penetration proportions are substantial, and 4) nearly all newly emerging safety technologies are offered both as optional and standard equipment during the introduction period.

This may be the first study of safety technology insertion patterns; the raw data and tabulated results should prove to be useful to regulators and manufacturers in planning for future safety technologies and scheduling rule driven lead time and phase in periods. The study is limited to models offered for sale in the United States market only. Rollover roof rail air bags are an exception in that throughout most of the introduction period, most applications were as standard equipment only.

MOTOR VEHICLE SAFETY AND PUBLIC HEALTH

The National Traffic and Motor Vehicle Safety Act was adopted in 1966. The law established the National Highway Traffic Safety Bureau, now the National Highway Traffic Safety Administration (NHTSA) to address the need for vehicle safety and required the NHTSA to promulgate motor vehicle rules to protect the public against "unreasonable risk of death or injury" in traffic collisions [1]. Following its Congressional mandate, the NHTSA has implemented a rules based structure that establishes specific requirements for safety performance at a vehicle, system, or component level. Vehicle manufacturers must certify that all products offered for sale satisfy those requirements. In doing so, manufacturers meet the safety need established by the NHTSA.

In many dimensions of safety performance and technology implementation, manufacturers have exceeded the specifications set in applicable rules and have implemented safety improvements not mandated by rule. By allowing motor vehicle manufacturers the flexibility to exceed rule based performance standards and to apply new safety equipment and technologies for which there are no regulations, the NHTSA promotes the advance of motor vehicle safety and progress in the science and application of motor vehicle collision injury control. Most regulatory requirements and safety improvements voluntarily implemented by motor vehicle manufacturers have been developed through the application of a public health model for injury reduction involving the following steps:

1. Collection and analysis of collision injury data to identify opportunities for improvement and prioritize safety needs.
2. Selection of priority safety improvement targets and application of research efforts to invent possible countermeasures.
3. Establishment of a staged research plan encompassing five elements: concept definition, requirements and specifications definition, technology development, feasibility and marketability assessments, and final validation for vehicle integration. Research is used in part to: size the safety improvement opportunity that might be offered by a technology concept and to define the operational parameters that characterize a safety need. In characterizing the operational parameters of a safety need, regulators and researchers can establish test conditions, evaluation criteria, and performance specifications for the technologies that are intended to address that particular safety opportunity.
4. Initiation of rule making, if started in advance of technology implementation schedules, and eventual finalization of rule making.
5. Development of technologies that satisfy established performance requirements and can be balanced with vehicle level imperatives (vehicle mass, package constraints, vehicle level performance metrics, direct material costs, etc.)
6. Creation of the supply chain necessary for materials, components, and systems that can be inserted into the Vehicle Development Process (VDP) and eventually support production applications.
7. Planning and execution of vehicle programs structured to integrate the newly developed safety technologies into the VDP and to provide a balanced vehicle with the new technology into the stream of commerce.
8. Once sufficient time has passed from implementation to collect a significant sample size, the countermeasure can be evaluated by collection and assessment of collision injury data and the process can begin again in identifying the next candidate opportunities and priorities.

It is not possible to establish test conditions, evaluation criteria, and performance specifications for every condition that might occur in real world traffic collisions. Therefore, regulators and safety researchers use collision data to characterize a particular safety need and then select specific test conditions, criteria, and performance specifications to control vehicle responses to that particular safety challenge. Test conditions, criteria, and performance specifications are set at the outer bounds of real world collision types to ensure that the applied technological solutions will be robust to many different real world collision conditions that are not specifically tested and evaluated in laboratory settings and comprehended in manufacturers' VDP for validation or certification. In this way, tests and acceptance criteria are established that apply to a broad range of collisions and affect a safety improvement for many more collision types than are replicated in the particular test itself.

This public health improvement process has been successfully applied in the U.S. over several decades. We can measure and judge the success of this injury reduction model by review of fatal injury rates over time. Figure 1 shows that the motor vehicle collision fatality rate has declined about 80 % over the period 1966 to 2009 [2].

Safety improvements have been realized due in part to improvements in: driver and occupant behaviors (seat belt use, child restraint use, and reduced drunk driving); roadway designs (highway design, roadway signage, traffic controls, roundabouts, overhead lighting, etc.); legislative and law enforcement initiatives (restraint laws, anti-drunk driving laws); public education efforts (National Safety Council, Safe Kids, the Airbag and Seat Belt Safety Campaign (ABSBSC), "Click it or Ticket," NHTSA and State programs); post collision treatment and care (emergency response times, comprehensive treatment at Level 1 trauma centers, automatic collision notification); and broad implementation of motor vehicle safety technologies (seat belts, structural collision performance criteria, fuel system integrity, supplemental restraints, electronic stability control, etc.). This paper reviews and compiles data regarding the patterns of safety technology insertion over the period 1998 through 2009.

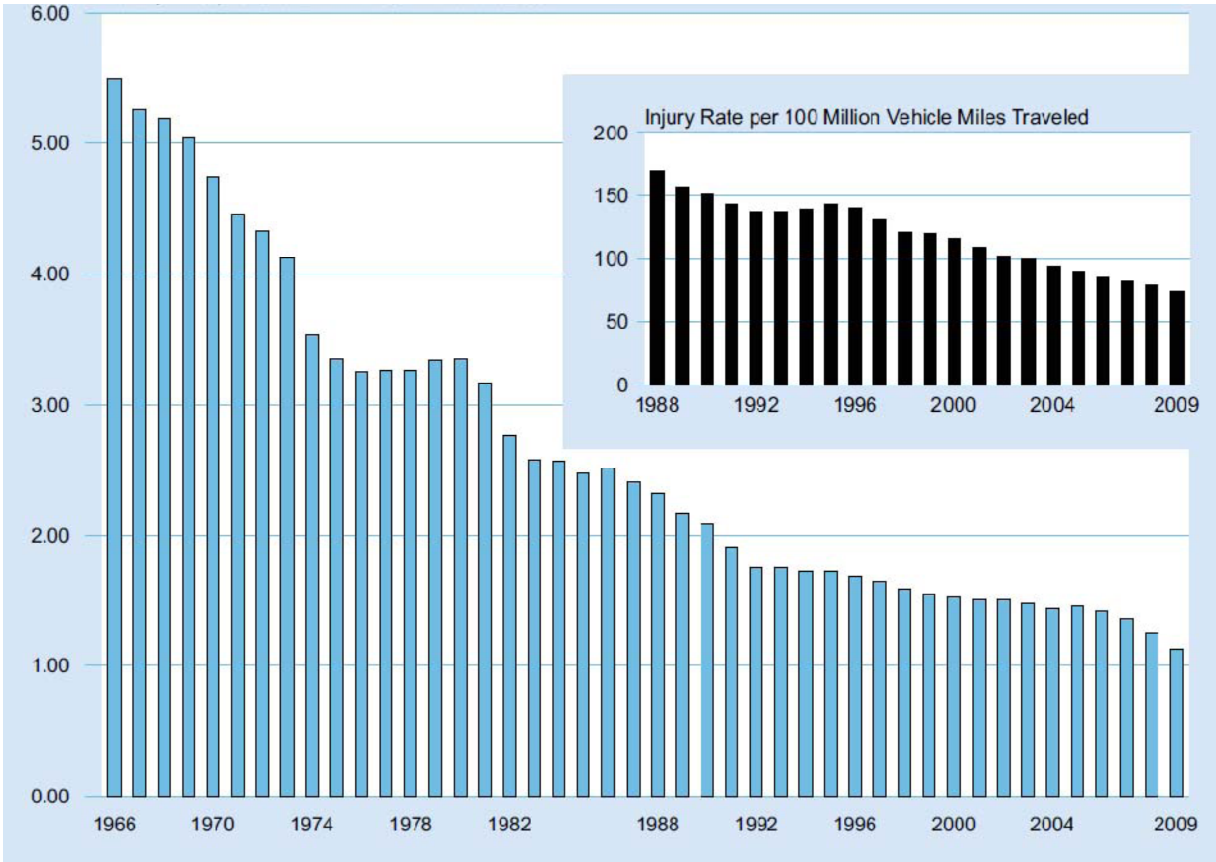

Figure 1. Fatality rate per 100 million vehicle miles traveled [2].

METHODOLOGY & DATA FORMAT

The goal in data collection was to compile a comprehensive and detailed list of safety technologies for all vehicles sold in the U.S. market. NHTSA's New Car Assessment Program (NCAP) database was identified as the best foundation on which to build. The NCAP database compiles data on about 28 different safety features for the vehicles tested each year in the program. Important information, though, is missing from this database. Since only a portion of all available models and body styles are tested, there was not a comprehensive list of all models and body styles available. There was no information on pricing, fuel economy, dimensions, weights, powertrains, or trim levels. Information was purchased from Ward's Automotive to supply this additional information. A time consuming, manual process was then undertaken to make the nomenclature for model and body style common between the two sets of data. The two sets of data were then combined in an Access database in a format capable of complex manipulation and future data update. The resulting database contains about 1.7 million cells of data.

One application of the database is to create a model year table of technology availability as shown in the table of side air bag availability shown in Table 1. All models offered in each model year in the survey are shown in the table and organized by brand and manufacturer. The model cells are filled in white if the technology was not available. They are filled in yellow if the technology is optional on any trim level. They are filled in green if the technology is standard equipment on all trim levels. For this table one specific body style was chosen for each model due to the limitation on the size of graphics. But data has been collected down one more level to body style as there are often important differences in technology applications between different body styles of the same model. One example is the technology of all belts to seats (ABTS). While sedans often do not employ this technology since belts can be anchored more efficiently to the B-pillar, coupes to some degree and convertibles in almost all cases do not have a B-pillar and are thus more likely to employ ABTS. Thus resolution down to body style is important.

Table 1.
2000 side air bag availability model table

Model Year 2000

Safety Technology: SAB Availability

									Camaro								
									Cavalier								
									Corvette								
									Impala								
Contour									Lumina								
Crown Victoria									Malibu								
Escort									Metro								
Escort ZX2									Monte								
Focus									Prizm								
Mustang									Astro								
Taurus									Express	Envoy							
Econoline									Blazer	Jimmy							
Excursion									S10	Safari							
Expedition	626	Cougar							Silverado	Savana		Bonneville					
Explorer	Miata	Mystique						Catera	C/K	Sierra		Firebird					
F-Series	Millenia	Grand	Continental	C70			Century	DeVille	Suburba	Sierra Classic	Alero	Grand Am		LS/LW		Accent	
F-Super-Duty	Protégé	Sable	LS	S70/V70		XJ-	LeSabre	Eldorado	Tahoe	Sonoma	Bravada	Grand Prix		SL/SW	Lanos	Elantra	Sephia
Ranger	B-Series	Mountaineer	Navigator	S80	Discovery	XK-	Park	Escalade	Tracker	Yukon	Intrigue	Montana	9-3	SC	Leganza	Sonata	Spectra
Windstar	MPV	Villager	Town Car	S40/V40	Range Rover	S-Type	Regal	Seville	Venture	Yukon XL	Silhouette	Sunfire	9-5	EV1	Nubira	Tiburon	Sportag
Ford	**Mazda**	**Mercury**	**Lincoln**	**Volvo**	**Land Rover**	**Jaguar**	**Buick**	**Cadillac**	**Chevrolet**	**GMC**	**Oldsmobile**	**Pontiac**	**Saab**	**Saturn**	**Daewoo**	**Hyundai**	**Kia**
Ford							GM								Daewoo	Hyundai	
US															South Korea		

							Avalon											
							Camry											
							Camry					Avenger						
							Celica					Intrepid						
Accord							Corolla					Neon			C-Class			
Civic			Altima				Echo					Stratus			CLK			
CR-V			Frontier				4Runner	ES300		Cirrus		Viper		Diamante	CL		Beetle	
Insight		Amigo	Maxima				Land	GS	3-Series	Concorde		Caravan		Eclipse	E-Class		Cabrio	
Odyssey	Integra	Hombre	Pathfinder	G20	Esteem	Forester	RAV4	SC	5-Series	300M	Breeze	Dakota		Galant	S-Class		EuroVan	A4
Passport	NSX	Rodeo	Quest	I30	Grand Vitara	Impreza	Sienna	LS400	7-Series	LHS	Neon	Durango	Cheroke	Mirage	SL		Golf/Gti	A6
Prelude	3.5RL	Trooper	Sentra	QX4	Swift	Legacy	Tacoma	RX300	X5	Sebring	Prowler	Ram Pickup	Grand	Montero	SLK	911	Jetta	A8
S2000	3.2TL	VehiCross	Xterra	Q45	Vitara	Outback	Tundra	LX470	Z3	Town & Country	Voyager	Ram Van &	Wrangler	Montero	M-Class	Boxster	Passat	TT
Honda	**Acura**	**Isuzu**	**Nissan**	**Infiniti**	**Suzuki**	**Subaru**	**Toyota**	**Lexus**	**BMW**	**Chrysler**	**Plymouth**	**Dodge**	**Jeep**	**Mitsubishi**	**Mercedes**	**Porsche**	**VW**	**Audi**
Honda		Isuzu	Nissan		Suzuki	Subaru	Toyota		BMW	Daimler AG						Porsche	VW	
Japan									Germany									

Green=Standard | Yellow=Optional

Another application of the database is to create a bar chart showing the insertion of the technology into the vehicle fleet over time. Figure 2 shows the insertion history for head curtain air bags. For each model year the optional and standard percentages of unique vehicle model body styles employing the technology are displayed.

The data collected is deep in detail. For example, side protection air bags are not simply listed as unavailable, optional, or standard. The detail specifying the availability, type of bag (torso, combo, or head curtain), seating position coverage, and source of deployment (seat, door or roof rail) add up to 110 unique identifying codes.

TECHNOLOGIES SURVEYED

The 28 technologies for which the database collected information are shown in Table 2.

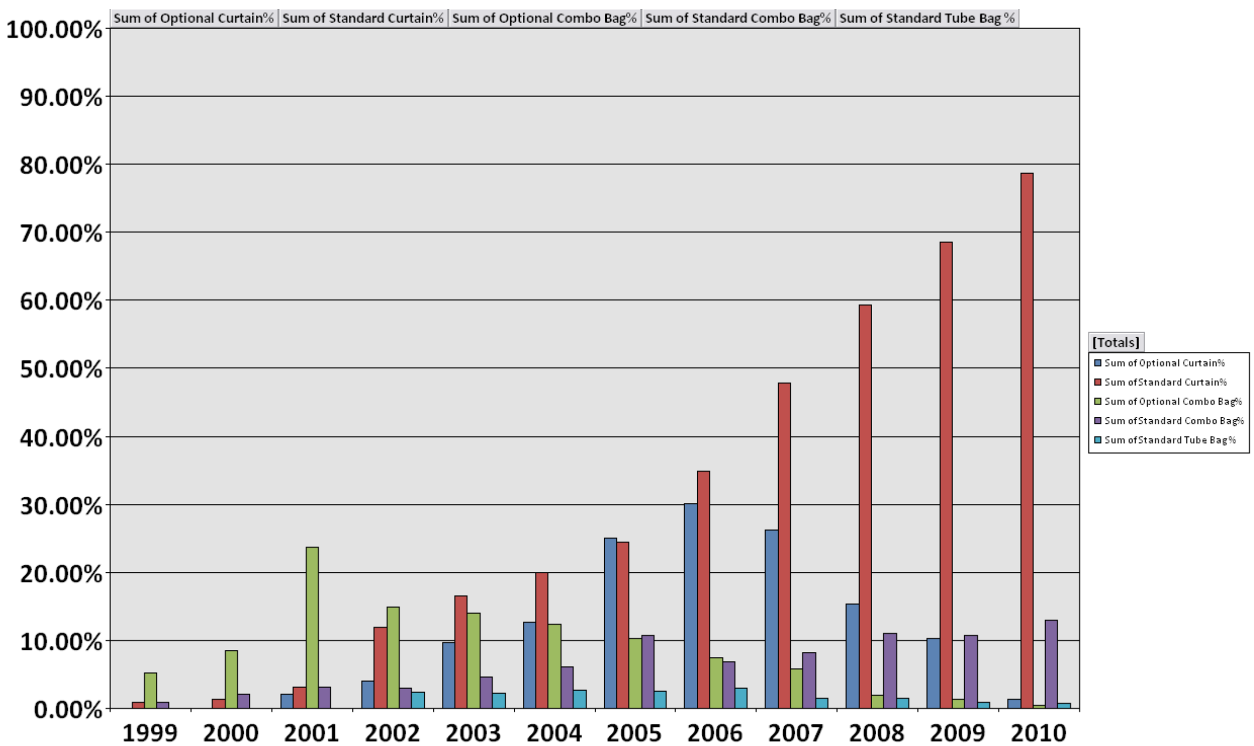

Figure 2. Head curtain, combo, and tube air bag availability.

Table 2.
Safety technologies compiled in database

ABS – 4 wheel	Collision warning frontal	Safety power windows
ABS – rear wheels	Collision warning rear	Seat belt energy management
Airbag – advanced features	Crash data recorder	Seat belt pretensioners
Airbag on/off switch	Daytime running lights	Side air bag
Auto crash notification	Dynamic head restraints	Stability control
Auto dim mirrors	Head curtain air bag	Tire pressure monitoring
Automatic door locks	Head curtain air bag rollover detection	Traction control
Brake assist	Lane departure warning	Trunk release
Built in child seat	Rear center lap-shoulder belt	
Camera	Rear seat head restraints	

INSERTION PATTERNS

In general, new safety technologies developed for insertion into the new vehicle fleet during the period 1998 through 2009 were phased in over lengthy periods of time, often extending throughout the entire decade. None of the new emerging safety technologies surveyed were adopted and inserted ubiquitously throughout the fleet in a single model year. Insertion patterns reflect a deliberate pace dictated by the constraint conditions identified above. Safety technologies of unknown efficacy and unknown potential adverse effects can be feathered into the vehicle fleet with limited early applications; thereby giving manufacturers opportunities to assess safety efficacy and to resolve questions over unanticipated adverse effects.

The insertion of new safety technologies is not unconstrained. The research and development processes must advance the state of knowledge regarding injury control science sufficiently to justify resource expenditures in research and development. Research must establish test procedures reasonably reflective of real world collision conditions and acceptance criteria related to safety improvements and achievable with engineered solutions that can be manufactured and integrated into production vehicles. Technology countermeasures must be engineered to be compatible with vehicle architectures and technologies or those incompatible architectures must be modified to accommodate new safety technologies. Technology and vehicle development processes must be configured to comprehend human, capital, and test capacity resource limitations. Unknowns regarding the effectiveness of new technologies often limit manufacturers' ability to adopt the technologies as benefits are difficult to define and promote. The pace of new safety technology insertion is dependent upon consumer acceptance and affordability, concerns regarding unanticipated consequences of the new technology and successful experiences in early applications to resolve those concerns. Regulatory activity can influence or inhibit the pace of technology insertion contingent upon the uncertainties regarding test requirements, acceptance criteria, reliability and repeatability of test procedures, and technology readiness to perform at a regulated level.

Consumer reactions and acceptance of new safety technologies cannot be accurately assessed until some models are introduced with new technologies; thereby motor vehicle manufacturers and the supply base can appropriately ramp up production capacities and capabilities to accommodate the additional demands imposed by new technology requirements. Phased in introduction facilitates movement downward on the cost curve with successive iterations of manufacturing and design efficiencies; instantaneous uniform introduction of a new technology would impose and institutionalize initial high cost levels upon the entire new vehicle fleet and supply base; efficiencies would be delayed for second and third round resource allocations rather than can be realized with successive generations of improved designs and efficiencies generated by rapid application of cyclic learnings.
For these and other reasons, many manufacturers and models adopt new safety technologies on an optional basis initially, and contingent upon market acceptance and competitive considerations, the optional technologies may migrate to standard equipment.

Figures 3 through 10 show the insertion patterns for eight of the safety technologies. Some technologies are collision avoidance technologies: Antilock Braking System (ABS), Electronic Stability Control (ESC), Tire Pressure Monitor Systems (TPMS), Daytime Running Lights (DRLs), and backup cameras that help prevent low speed collisions with near objects in reverse. Others are crashworthiness technologies: side air bags, head curtain air bags (Figure 2), and seat belt pretensioners. Finally, automatic collision notification improves emergency medical service response to a collision.

CONCLUSIONS AND OBSERVATIONS

Some injury mitigation technologies started in application prior to the first year of registration in the database we have constructed, for example ABS.

Injury mitigation technologies of the same character may vary substantially in specific execution; see for example the type variations for side impact air bags.

Installation of injury mitigation technologies often is initiated by individual manufacturers in advance of rule making. Successful safety technologies grow in application over time.

Injury mitigation technologies are often introduced into the stream of commerce as optional equipment and as standard equipment. The only observed exception registered in this survey is the installation pattern for front seat safety belt pretensioners.

REFERENCES

[1] Laws of the 89th Congress 2nd Session. "National Traffic and Motor Vehicle Safety Act of 1966. 1966.

[2] NHTSA. "Traffic Safety Facts 2009. 2009.

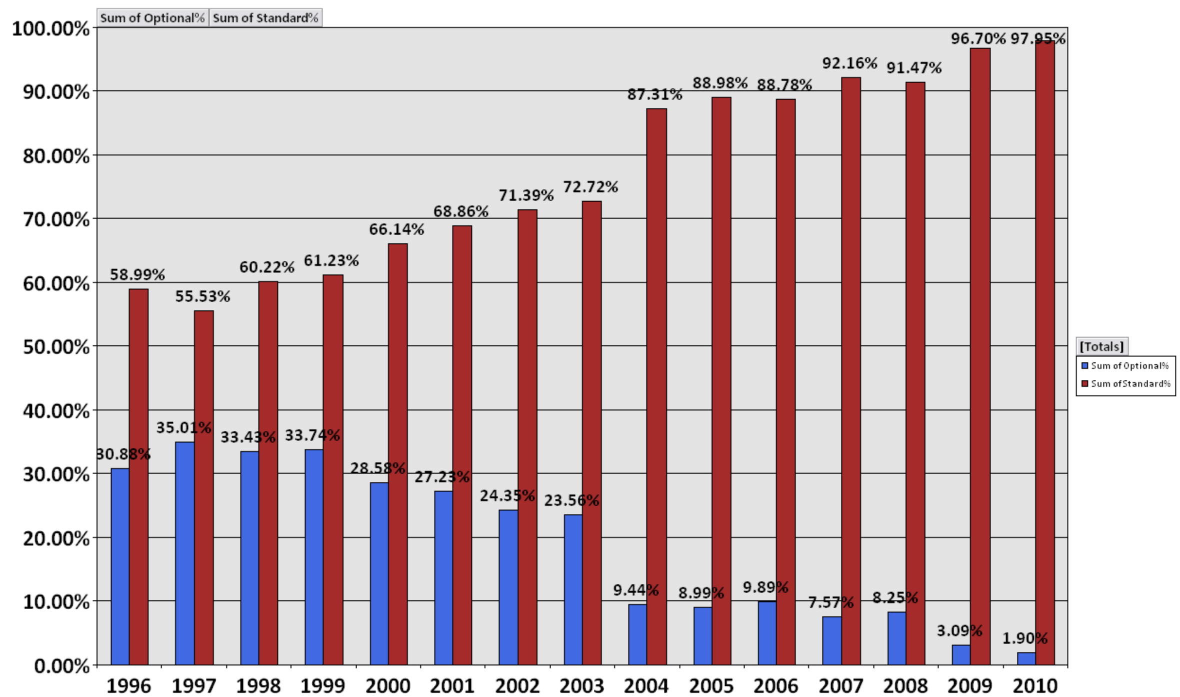

Figure 3. ABS technology insertion by model year.

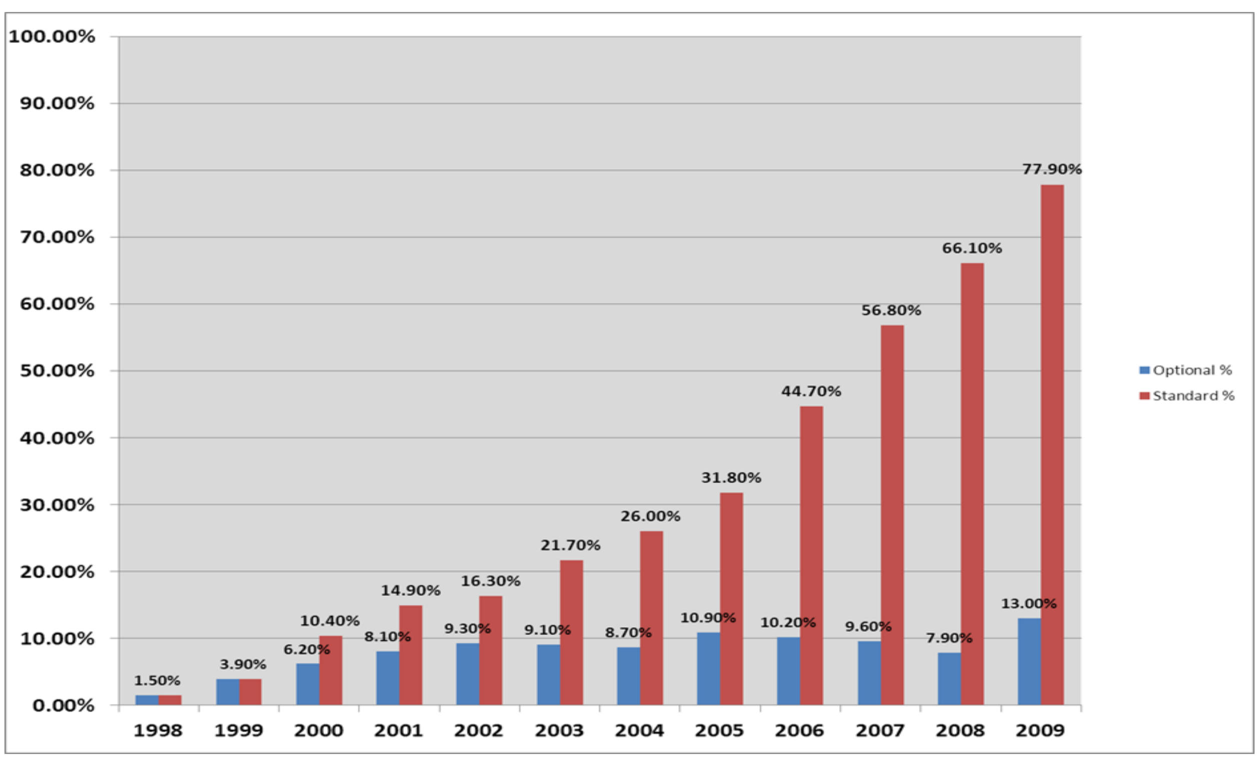

Figure 4. Electronic stability control technology insertion by model year.

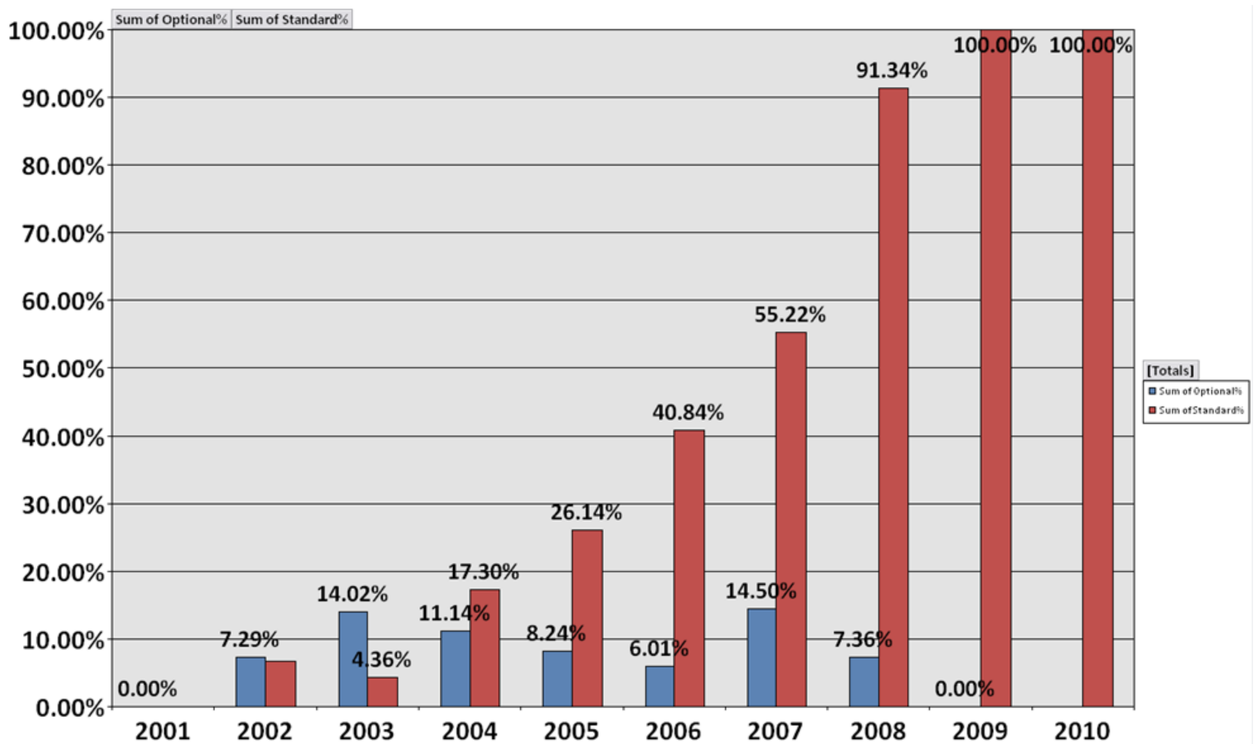

Figure 5. Tire pressure monitoring technology insertion by model year.

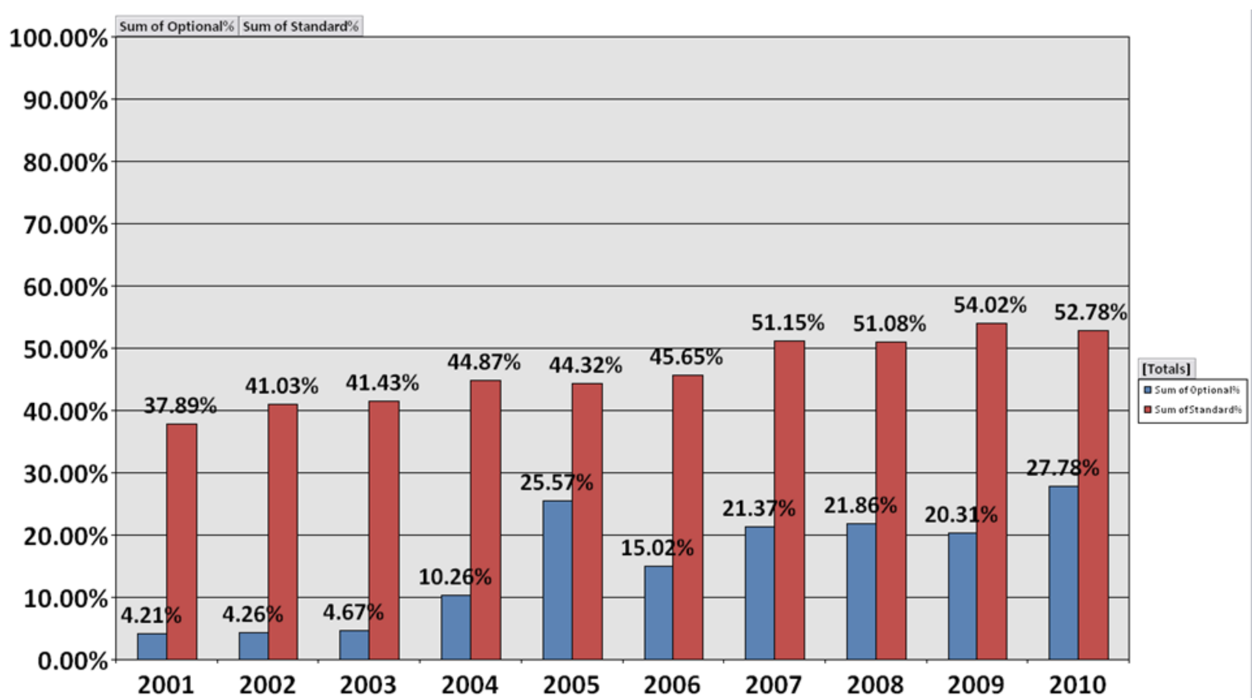

Figure 6. Daytime running lights technology insertion by model year.

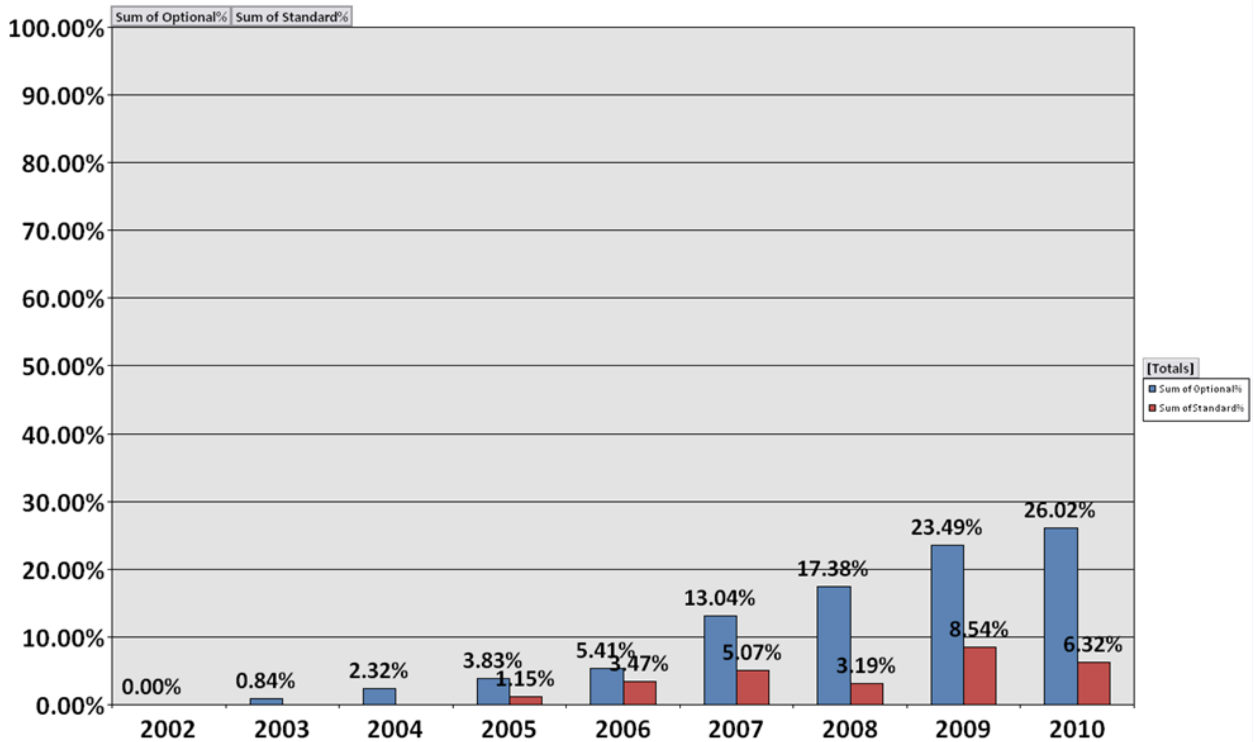

Figure 7. Backup camera technology insertion by model year.

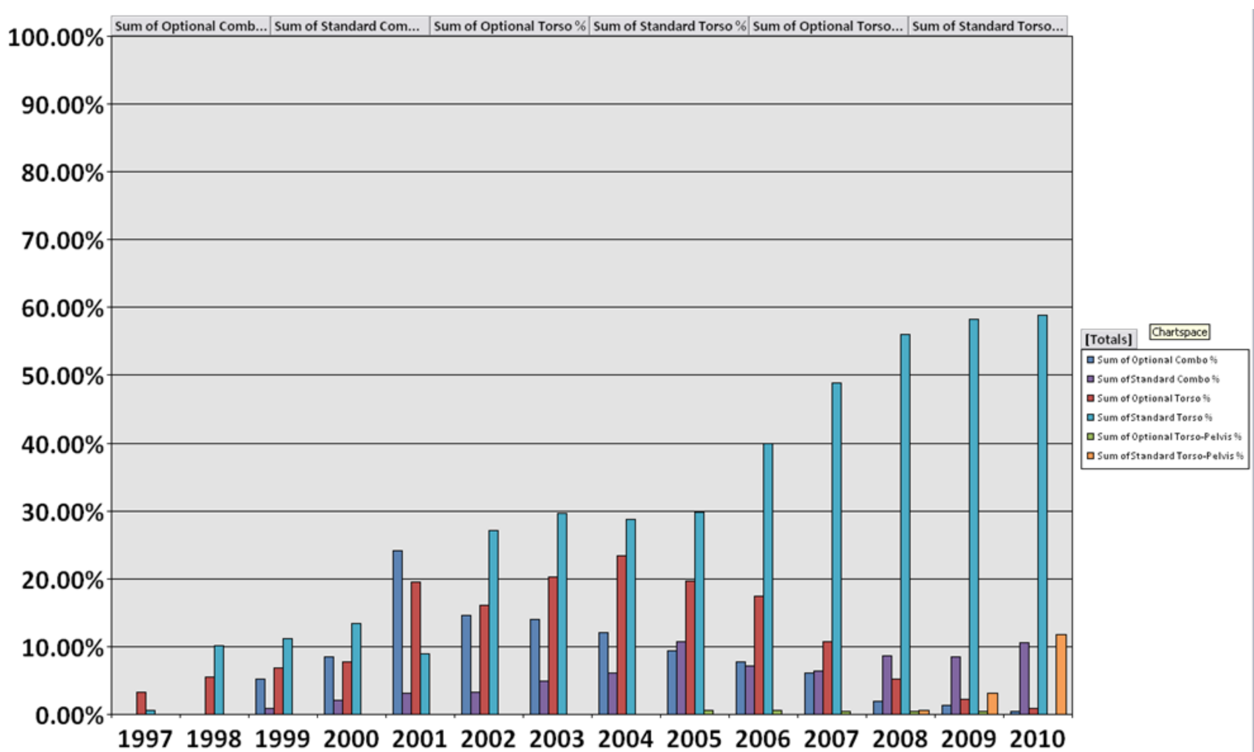

Figure 8. Side air bag technology insertion by model year.

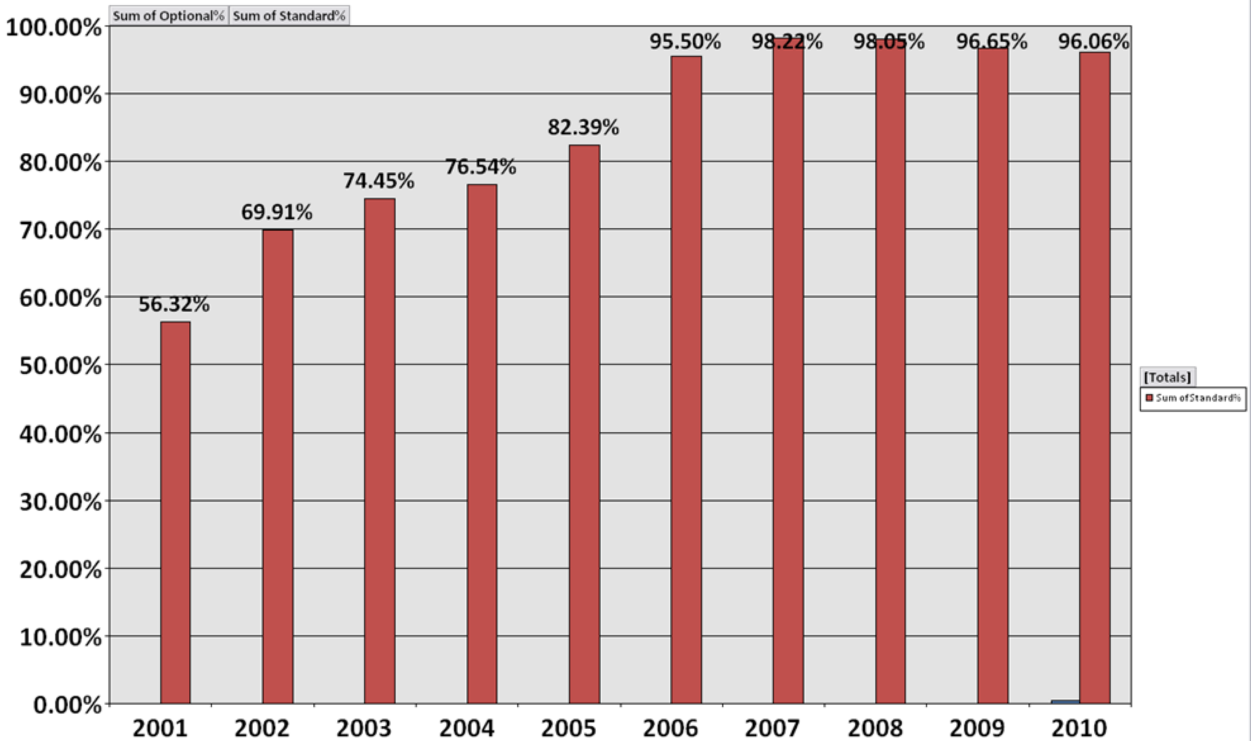

Figure 9. Seat belt pretentioner technology insertion by model year.

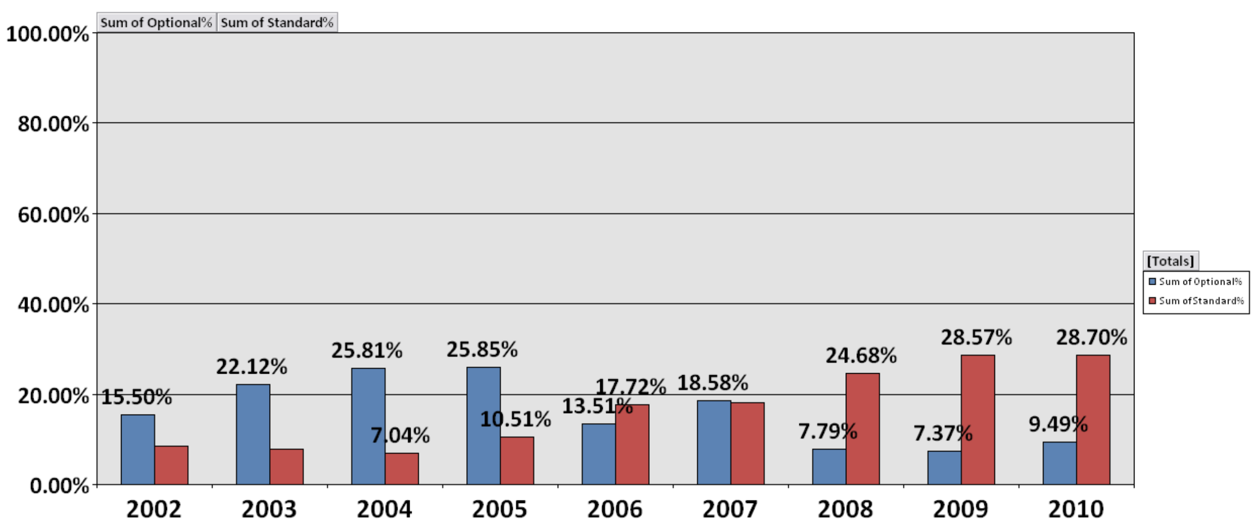

Figure 10. Auto crash notification technology insertion by model year.

APPLICATION OF ANCAP STAR RATINGS TO VARIANTS OF VEHICLE MODELS

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ABSTRACT

The Australasian New Car Assessment Program (ANCAP) crash tests vehicles and assigns an occupant protection rating out of five stars. Most NCAP organisations usually only test and rate one variant of a vehicle model. Other variants may differ from the tested vehicle in a number of ways. These factors include: body style, engine, transmission, mass and mass distribution, safety features and crashworthiness-related structure. They can all be expected to influence the crash test results to some degree. Historically, NCAPs around the world have not made any claims or statements about these untested variants. There is an increasing demand for information about the star rating of non-tested variants of models. One reason is that many vehicle fleets now insist on a minimum 4- or 5-star rating for the new vehicles that they purchase. During 2009 a working group of ANCAP considered ways in which a star rating could be extended from the tested variant to other variants. This paper sets out the results of that review and the policy that has now been published by ANCAP. This policy allows the rating of many more variants and provides benefits for consumers, ANCAP and vehicle manufacturers.

KEYWORDS

ANCAP, NCAP, crash testing ratings, occupant protection

INTRODUCTION

NCAP organisations usually test and rate one variant of a vehicle model. Other variants may differ from the tested vehicle in a number of ways. These include: body style, engine, transmission (including 4x4 vs 4x2), left- or right-hand drive, mass and mass distribution, and safety features. These can all be expected to influence the crash test results to some degree. Generally NCAPs do not make any claims or statements about non-tested variants.

"Stars on cars" programs, where NCAP ratings are displayed on vehicles in showrooms, can be limited by the lack of published ratings for some variants of a model. Furthermore, increasingly as vehicles achieve top ratings, manufacturers are keen to have these ratings apply to other variants of the model.

To determine the star rating of variants, one option is for manufacturers to sponsor additional NCAP crash tests of these variants. However, to minimise the need to do this with the associated costs, it would be beneficial if there were agreed guidelines to determine the untested model variants that can be rated by ANCAP, based on results from a tested vehicle variant.

This document sets out ANCAP policy for these situations.

METHOD

The likely influence of key factors is considered in Table 1, together with criteria that should be met in order for the variant to receive the same rating as the tested variant. In some cases, the variant might receive a lower score and possibly a lower star rating than the tested variant.

Where any of the criteria in Table 1 are not met, additional evidence is required as set out in the Appendix.

Table 1.
Criteria for comparable occupant protection

Factor	Criterion
a) Body style (e.g. 3-door hatch, 5-door hatch, sedan, coupe, wagon)	For the purpose of assessment a transverse vertical plane is defined that is 500mm rearward of the upper seat belt anchorage point for the driver seat. Forward of this plane, variants must be identical in design and structure for crashworthiness purposes. A statement from the manufacturer is acceptable for this purpose, subject to visual verification. This includes the front seat belt anchorages but not rear seat belt anchorages. For example, a 3 door hatch result cannot be used for a 5 door hatch variant and vice-versa, without *additional evidence for all tests*. However, a sedan or wagon variant might be interchangeable with a 5 door hatch.
b) Kerb mass	Variation up to ±10% is allowed.
c) Engine (displacement, cylinder configuration, aspiration, block size, type of fuel)	The same block size & configuration is allowed, irrespective of displacement, aspiration and fuel. Extra components within the engine bay such as LPG convertors and turbo-chargers are acceptable provided that footwell and pedal intrusion are well controlled in the tested vehicle (i.e. 4 points scored for driver's feet - this means that pedal rearward displacement is under 100mm and there is no footwell rupture). Note that a 4 cylinder result cannot be used for a V6 result and a V6 result cannot be used for a V8, and vice versa, without *additional evidence for the offset test*. Engine differences are acceptable for the side impact and pole tests. For the pedestrian protection rating, components that reduce the bonnet clearance and/or stiffness of a bonnet impact will be assessed. Extra head impact tests might be undertaken at ANCAP's discretion.
d) Transmission (manual or auto, number of gears)	Any transmission is acceptable. Note that ANCAP policy for selection of test vehicles is that an automatic transmission will only be selected if at least 80% of that variant's sales are automatic.
e) Driven wheels (4x4, 4x2, front-wheel drive, rear wheel drive)	Two wheel drive results (either front or rear) are not interchangeable with an all-wheel-drive variant without *additional evidence* (*offset test*) due to the effect of the rear driveline. Similarly front-wheel drive results are not interchangeable with rear-wheel-drive results, without *additional evidence*. Driven wheel differences are acceptable for the side impact and pole tests.
f) Ride height (eg height of top of wheel arch) and tyre diameter	*Offset test* acceptable provided that the ride height does not vary by more than +/-50mm from the tested variant. *Side impact test* of lowest variant may be used for other variants up to the point where the default score is used for a high-seat vehicle*.
g) Wheelbase	Wheelbase variation up to ±100mm is acceptable.
h) Driver location (left-hand-drive, right-hand drive)	Where ANCAP has published a rating based on crash tests of a left-hand-drive (LHD) variant, that rating may be applied to other variants in Australasia subject to meeting the relevant criteria in this table.
i) Front occupant restraint systems	Subject to items j to m, installed airbags must be the same as the tested variant, or better. For example, for the purpose of the side impact test, curtains may be fitted where the tested variant had seat-mounted side airbags with head protection. However, *additional evidence* is required for the pole test, where the type of head-protecting side airbag is different. Front seat belt pretensioners and load limiters must be identical. Front seat belt anchorages must be identical in geometry and adjustment features. Seat design must have similar restraint-related features, such as anti-submarining pans. Upholstery and adjustment features may vary.
j) Lack of	*Offset test* results for a variant with a front passenger airbag may be used for a

passenger front airbag	variant without a front passenger airbag but a score deduction normally applies. Where a Euro NCAP tested variant had a front passenger airbag and the variant being assessed does not have this then a 2-point deduction is applied to the front passenger head score (*offset test*), unless *additional evidence* is provided (new policy).
k) Lack of head-protecting side airbag (not high seat vehicle*)	Where a tested variant had a head-protecting side airbag and the variant being assessed does not have this then a 2-point deduction is applied to the head score (*side impact test*), unless *additional evidence* is provided (new policy). Test data from an acceptable Australian Design Rule (ADR) 72 crash test would be suitable for this purpose.
l) Lack of thorax-protecting side airbag (not high seat vehicle*)	Where a tested variant had a thorax-protecting side airbag and the variant being assessed does not have this then a 2-point deduction is applied to the chest score (*side impact test*), unless *additional evidence* is provided (new policy). Acceptable ADR72 test data would be suitable for this purpose but 2-point deduction applies where these data do not include dummy backplate or T12 measurements.
m) Lack of knee airbag	Where a tested variant had a knee airbag and the variant being assessed does not have this feature available then a 2 point deduction is applied to the driver/passenger upper leg score (*offset test*) unless *additional evidence* is provided (existing ANCAP policy).
n) Other safety features	Intelligent seat belt reminders are assessed and scored for each variant. Therefore variants with different numbers of seat belt reminders will have different scores. ESC is required for a 5 star rating. Variants that miss out on 5-star due to a lack of ESC can only obtain a maximum 4-star rating (overall score 32.49 points). Similar arrangements will apply if ANCAP introduces additional qualifiers for a star rating. In the case of station wagons and vans that are car derivatives, a 5-star rating will only be available where that variant has a cargo barrier (standard or optional equipment) that complies with AS 3034 (or acceptable equivalent).

* "High seat vehicle" is a vehicle with a seating reference height more than 700mm which is therefore exempt from the ADR72 regulatory side impact test. ANCAP applies a default 16 points for these vehicles, unless a EuroNCAP test result is available that is less than 16 points.

CONCLUSIONS

Extending the ANCAP rating of a vehicle model to a range of variants through the examination of data has several positive outcomes. It provides more information for consumers when they wish to purchase a vehicle, it extends ANCAP's range of results at minimal cost and it provides a route for manufacturers to have more of their vehicles rated at comparatively low cost.

APPENDIX

Additional evidence to be provided by the vehicle manufacturer

The manufacturer's submission should address each of the technical items set out in Table 1, indicating whether the criteria are met.

Where a manufacturer seeks to apply an ANCAP rating to a variant that does not meet the criteria set out in Table 1, further engineering evidence is required to show that the additional variant provides at least the same level of occupant protection as the tested variant for the type of crash test under consideration.

Additional evidence may also be submitted where ANCAP proposed to use default deductions due to a lack of side airbags (j, k, l & m in Table 1).

Manufacturers may also submit evidence to show that an ANCAP rating should not be applied to a particular variant, despite it meeting the criteria of Table 1.

Submissions from manufacturers will be circulated within the ANCAP Technical Working Group on a confidential basis.

Crash performance comparisons

The main purpose of the test data is to show comparable performance so that the existing ANCAP test results can be applied to the additional variant or to show that the additional variant performs better than that derived from a default score (e.g. where ANCAP proposes to apply a 2-point deduction due to the absence of airbags). Manufacturer's test data is not acceptable for deriving a *higher* star rating for an additional variant - only ANCAP or other acceptable NCAP test data may be used for this purpose.

Acceptable engineering comparisons include:

a) Crash tests for related regulation compliance tests, at regulation speeds or higher (such as ADR72 and ADR73)
b) Crash tests at NCAP speeds conducted according to ANCAP/Euro NCAP protocols by or on behalf of the manufacturer at an approved test facility (e.g. acceptable for ADR certification purposes)
c) A Federal Motor Vehicle Safety Standard (FMVSS) 214 Oblique Pole Test may be used to demonstrate the effectiveness of a head-protecting side airbag/curtain, as an alternative to a Euro NCAP-style pole test.
d) Results of computer modelling should show comparable structural deformation (including footwell and firewall) and vehicle body deceleration. Mathematical Dynamic Models (MADYMO) modelling, or equivalent, of dummy responses is preferred.

The tested models should be built to Australian specifications, but overseas specifications (e.g. comparisons between two LHD variants) may be acceptable.

Manufacturers' representatives are encouraged to contact ANCAP to discuss the types of evidence that are proposed to be submitted. Generally only summary test data, that identifies the vehicle, the type of test, the test facility and the key injury measurements, is required by ANCAP.

Crash test comparisons

Where crash tests are compared the injury values for the additional variant should not exceed 110% of those in the ANCAP-tested variant unless:

1. the resulting injury scores are in the good range (i.e. score 4 points under the ANCAP assessment protocol) or
2. the resulting crash test and overall scores for the variant are sufficient to retain the same star rating as the tested variant

ASSESSMENT OF 12 YEARS KNCAP PERFORMANCES AND PLAN FOR ELDERLY OCCUPANT PROTECTIONS

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ABSTRACT

In 1999, Korea government has been established KNCAP program to promote vehicle safety enhancement and to reduce road traffic fatality. Currently, total 8 test protocols are available to evaluate vehicle safety performances including the two types of frontal crash test and side pole test. As results of the reinforcement of safety issues, the average KNCAP vehicle safety rate reaches about 4.5 star ratings. Furthermore, from 2010, the overall crash performance assessment rating system was adapted to clear understanding of the KNCAP results with the voluntary labeling system which similar to US labeling system.

However, in terms of elderly occupant's safety, the fatality rate is much higher than other age group. Conjunction with the current Korean elderly occupant protection research program, which initiated by the government resource 5 years ago, the assessment tool, may also include protecting a vulnerable road user, especially elderly drivers or occupants.

Recent researches show that the elderly occupant rib cage is relatively weak and fragile compared to the nominal adult age group. The current larger mass and stiff front structure of vehicle design required pretensioner belt system with relatively higher load limiter. When this belt restraint system with airbag were subjected to the anthropometric dummies such as Hybrid III 50%tile male or 5%tile female dummy, the injury performance were in excellent rate thus expected in good occupant protection in the real traffic accidents. However, in the real field, the fatality of elderly is more than 10 times higher than other age groups. The most frequent injuries are thoracic trauma, rib fractures due to the severe rib deflections.

The objective of our study was investigate rating criterion for pretensioner and load limiter performance for elderly occupant protections to define requirements for an optimal belt loading forces, and to quantify the benefits for elderly occupants within KNCAP testing system.

INTRODUCTION

The Korean New car Assessment Program (KNCAP) has been one of the most market influencing factors in the aspects of safety issues as well as industries safety technology adoptions in their new vehicles. The results of KNCAP ratings were published twice a year and also provide information on proper use of safety devices in order to enhance user's awareness and correct understanding on safety related devices such as airbag, ABS and seat belts. At the beginning, KNCAP test protocol and evaluation methods are similar to the previous USA NCAP and only passenger car category was tested. In the motor vehicle management act (Article 32-2), the KNCAP has been legal basis in 2002.

In 2005, up to 4.5 tons of buses and vans were included in the K-NCAP and not more than 1.0 ton truck was added as a test vehicle in 2007. This means that 87% of all buses and 72 % of trucks and 100% of passenger vehicles can be covered and evaluated safety performances within KNCAP system. Thus KNCAP covered 95% of all possible vehicle types. The Figure 1 shows that the expansion of vehicle category in KNCAP.

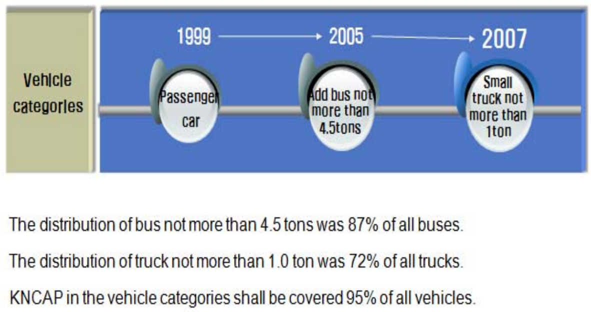

Figure 1. Vehicle categories in KNCAP

The test items were only the full wrap frontal crash test and braking test until 2002, however, with 55kph impact speed side crash test was added in 2003. In 2005, static roller test for roller protection and static measurements of head restraint's heights and backset test were introduced as a part of KNCAP. Since the majority of traffic fatalities were results from car to pedestrian accidents, the pedestrian head impact test and leg impact test were added in 2007 and 2008 conjunction with WP29 GTR harmonization. This year, the pedestrian head test will be added to evaluate the protection of pedestrian. In 2008, the head restraint test was updated with the dynamic test. Recently, 64km/h frontal offset test was also added to insure the front seat occupant protections in 2009. Finally, last year as an optional test, 90 degree side pole test was adopted as shown in Figure 2.

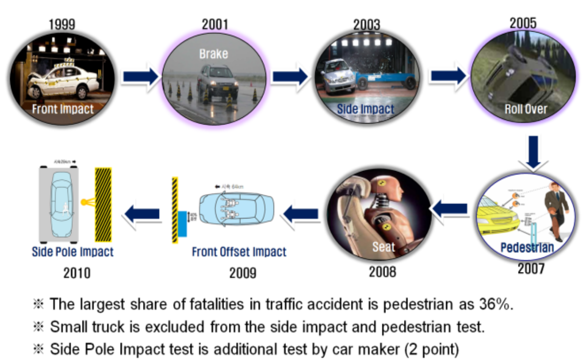

Figure 2. Expansion of KNCAP Items

For clear understanding of test results and degree of safety performance, in 2010, the overall crash performance rating system has been introduced and the total rating system including the active safety features will be adopted in 2013.

Enhancement of Frontal Crashworthiness

2010 KNCAP, the total 12 new vehicle were tested including 3 imported passenger vehicles. The selections of vehicle are based on the untested vehicle, sale volumes. The base (or minimum safety devices) design vehicle of the selected vehicle model will be tested. The all 12 KNCAP test result is shown in Table 1.

Table 1. 2010 KNCAP Test Results

2010		Test Items								
		Crash Test							Pre-Safety Test	
Class	Vehicle	Full Frontal	Offset Frontal	90° Side	Whiplash	Side Pole	Overall	Pedestrian	Rollover	Braking Distance (Dry /Wet)
SC	GM-D **Matis**	★★★★★ (15.1, 94%)	★★★★★ (14.3, 89%)	★★★★★ (15.0, 94%)	★★★★ (4.8, 80%)		Class 1 (49.2, 91%)	★★★★ (20, 67%)		45.7m / 50.7m
C	R-S **SM3**	★★★★ (12.5, 78%)	★★★★★ (14.2, 89%)	★★★★★ (14.1, 88%)	★★★★ (4.4, 73%)		Class 2 (45.2, 84%)	★★★ (13, 43%)		45.3m / 47.8m
	Hyundai **Avante**	★★★★★ (15.8, 99%)	★★★★★ (14.8, 93%)	★★★★★ (15.8, 99%)	★★★★★ (5.0, 83%)	2.0, 100%	Class 1 (53.4, 99%)	★★★ (14, 47%)		41.5m / 42.6m
M	Kia **K5**	★★★★★ (15.7, 98%)	★★★★★ (15.0, 94%)	★★★★★ (15.4, 96%)	★★★★★ (5.2, 87%)	2.0, 100%	Class 1 (53.3, 99%)	★★★ (18, 60%)		43.3m / 43.7m
	R-S **SM5**	★★★★★ (13.4, 84%)	★★★★★ (14.7, 92%)	★★★★★ (15.8, 99%)	★★★ (3.8, 63%)	2.0, 100%	Class 1 (49.7, 92%)	★★ (9, 30%)		43.1m / 44.6m
	Hyundai **Sonata**	★★★★★ (16.0, 100%)	★★★★★ (15.2, 95%)	★★★★★ (15.3, 96%)	★★★★★ (5.1, 85%)	2.0, 100%	Class 1 (53.6, 99%)	★★★ (13, 43%)		45.8m / 46.7m
M (RV)	Kia **Sportige**	★★★★★ (15.2, 95%)	★★★★★ (14.5, 91%)	★★★★★ (15.6, 98%)	★★★★★ (5.3, 88%)		Class 1 (50.6, 94%)	★★★★ (21, 70%)	★★★★ (15.0%)	42.5m / 43.5m
	Hyundai **Tucson**	★★★★★ (14.8, 93%)	★★★★★ (15.2, 95%)	★★★★★ (15.0, 94%)	★★★★★ (5.3, 88%)		Class 1 (50.3, 93%)	★★★ (15, 50%)	★★★★ (16.4%)	44.1m / 48.1m
L	Kia **K7**	★★★★★ (15.2, 95%)	★★★★★ (15.5, 97%)	★★★★★ (16.0, 100%)	★★★★★ (5.0, 83%)	2.0, 100%	Class 1 (53.7, 99%)	★★★ (18, 60%)		45.8m / 47.6m
	Lexus **ES350**	★★★★★ (16.0, 100%)	★★★★★ (14.6, 91%)	★★★★★ (16.0, 100%)	★★ (3.0, 50%)		Class 1 (49.6, 92%)	★★ (10, 33%)		45.2m / 49.2m
	Benz **E220 CDI**	★★★★ (12.2, 76%)	★★★★★ (14.3, 89%)	★★★★★ (16.0, 100%)	★★★★ (4.5, 75%)	2.0, 100%	Class 1 (49.0, 91%)	★★ (9, 30%)		42.2m / 46.2m
	Audi **A6**	★★★★ (12.9, 81%)	★★★★★ (15.1, 94%)	★★★★★ (15.4, 96%)	★★★ (3.6, 60%)		Class 1 (47.0, 87%)	★ (0, 0%)		38.6m / 42.7m

In the frontal crash test, for driver side occupant, the probability of severe injury was 16.4% improvement compared with that of 1999 to 2003 average results. In terms of star rating in 2010, 0.3 stars were increased. On the passenger side occupant, the likelihood of severe injury can be reduced up to 51.6% compared with results of 1999 through 2003 as shown in Table 2 and Figure 3.

The offset frontal test, all 12 vehicles achieved 5 stars but, in the full wrap rigid barrier test, 2 imported vehicles get 4 stars. But 1 domestic vehicle gets 3 star ratings (after re-test procedure, get 4 star).

Table 2. Frontal Occupants Safety Improvements (avg. 1999-2003 vs. 2010)

		Frontal Crash		Improvement (% or Star)	Reduction %
		'99-'03	'10		
Driver	Probability of Severe Injury(%)	18.3	15.3	3	16.4
	Avg. Star	3.8	4.1	0.3	7.9
Front passenger	Probability of Severe Injury(%)	25.0	12.1	12.9	51.6
	Avg. Star	3.2	4.3	1.1	34.4
Sum of Probability of Severe Injury(%)		21.6	13.7	8.0	37.0

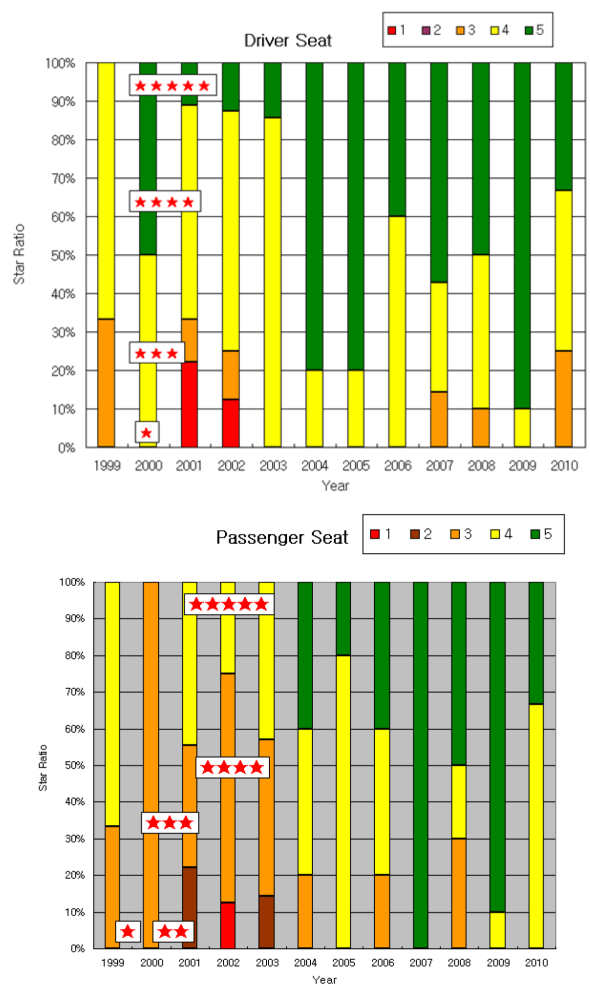

Figure 3. Trends of Star rating in Frontal Crash

TRENDS OF KOREA TRAFFIC ACCIDENTS AND ELDERLY OCCUPANT INJURY PATTERNS

Competition among car makers for the safer performances in line of KNCAP, the number of fatality and serious injury can be reduced. According to Nation police reports, the fatality of traffic accidents is gradually reduced year by year. Although the significant number of total registered vehicle is increased annually, in 2009, the total death from the traffic accidents was 5,838 (2008: 5,870) as shown in Figure 4. Results from the increased total traffic volume, the number of traffic accident and injury is still gradually increased every year.

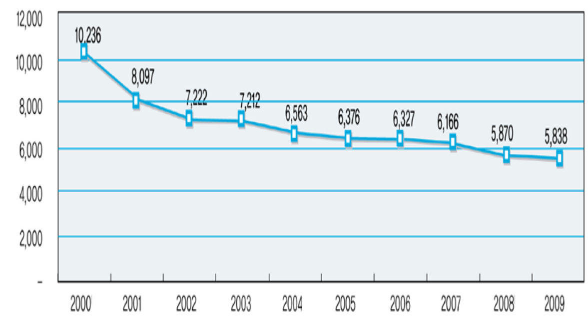

Figure 4. Trends of Traffic Fatality in Korea

The pedestrian fatality was about 35% while the fatality from car-to-car accident is the most frequent source of fatality, 43.6% (2,546). The remaining 21% of fatality was from the single vehicle involved accidents as shown in Figure 5.

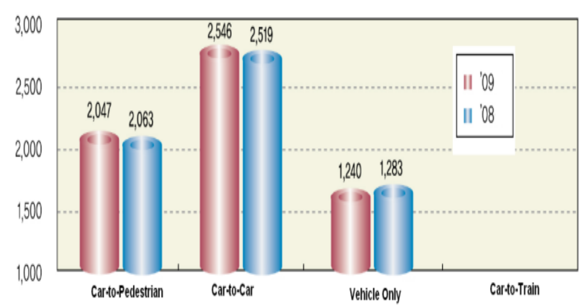

Figure 5. Accident Type of Traffic Fatality

Increase of Elderly Involved Traffic accidents

From 2005 national census, the population of 65 years and more (65+) was reached 4.3 million (9.1%) and entered aging society. Due the current extremely lower birth rate, the aging rate is rapidly increased. The most demographic forecasts indicate the proportion of Korean over 65 years of age by the year 2019 will be more than 14% of total population as an aged society.

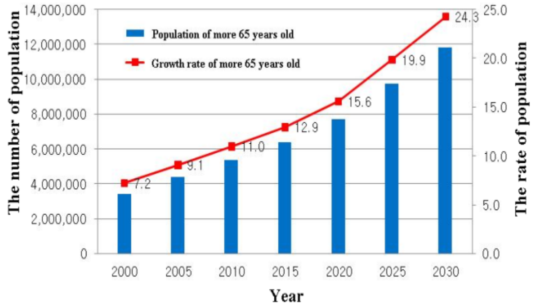

Figure 6. Elderly Population in Korea.

Therefore, it will become increasingly more important that safety standards or other assessment methods be optimized to mitigate elderly casualties. Unlike EuroNCAP, KNCAP does not account abnormal behaviors of occupant or safety devices during the crash test in the scoring system. The modifier was not adopted in KNCAP due to the possible argument of subjective opinions on the application of modifier.

Currently, in KNCAP 50%tile Hybrid III dummy was used to evaluate vehicle safety performances. Now, there are no criteria or weighting factors to be considered other than Hybrid III standard male dummy. Since, the number of elderly drivers (and/or passengers) or small frame of female drivers (and/or passengers) are continuously increased. by every year. Elderly drivers and passengers have a disproportionately higher crash involvement rate and commonly sustain more severe injuries than the general population.

From the National Police Reported Accident Data for the years 1994 to 2006, the fatality of the age group 61 and older (61+) was continuously increased 1,748 (17.3%) to 2,136 (33.8%). Still, the majority of elderly fatality is coming from the pedestrian casualty, however, the number of fatalities and seriously injured elderly occupants are rapidly increasing year by year.

In 2009, the elderly traffic causality was 1,826. It is 31% of total fatality. If consider the only fatality of elderly occupant (in vehicle), the ratio is 15%.

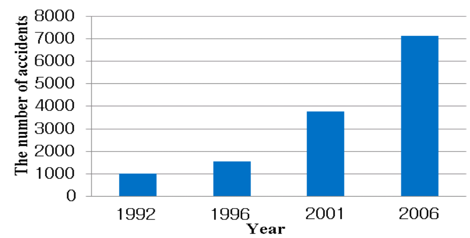

Figure 7. The Number of Korean Elderly Involved in Accidents.

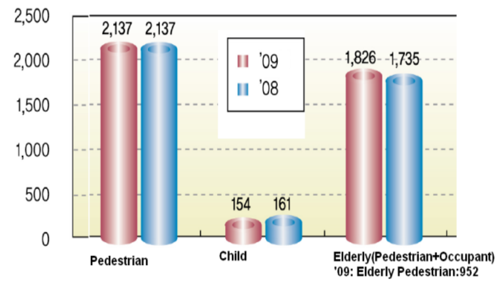

Figure 8. Fatality of Elderly Accidents

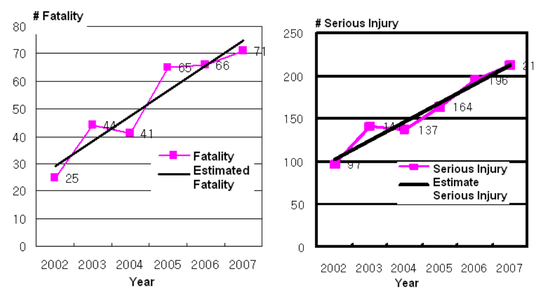

Figure 9. Estimated Trends of Fatality and Serious Injury of Elderly Accidents

Therefore, providing mobility as well as improvement of safety for older occupants is essential for aging society. To provide the safety for the elderly occupants, it will be necessary to review the injury criteria and safety standards to mitigate elderly casualties. Currently, the injury criteria in KMVSS are determined by Hybrid III 50%tile dummy readings similar to other countries.

INJURY PATTERNS OF THE ELDERLY OCCUPANTS

The risk curve, based on serious casualty data, exaggerates older drivers' crash involvement because of the 'frailty bias'. Because older people are more readily injured by a given physical impact, proportionally more of their total crashes have serious casualty outcomes. Many of research suggest that around one-half of the heightened fatality risk of drivers aged 75 years and more might be due to frailty rather than to unsafe driving practices. The same correction can be made to older drivers' involvement in non-fatal serious injury crashes.

Aging is a complex process which yields numerous mental and physical changes. In the present study, only physical changes were considered (e.g., geometrical, material, and structural). A number of studies have shown that, with increasing age, the energy-absorbing capacity of body structures generally declines.

Burstein, Reilly, and Martens concluded that there was a 5% decrease in the fracture strain per decade in the femur and a 7% decrease for the tibia. Zhou, Rouhana, and Melvin reviewed a number of aging functions of the femur bone and showed that the maximum bone strength occurs at approximately 35 years of age. The bone strength then begins to decline, with the rate of decline increasing significantly after 60 years of age. Zhou et al. also determined that the human soft tissues follow a similar trend.

Although older drivers are involved in relatively few collisions due to limited exposure, once involved in a crash they are more likely to sustain severe injuries or death (Cunninghan *et al.*). Several studies have confirmed that as people age, they are more likely to sustain serious or fatal injuries from the same severity crash (Evans, Evans, Bedard *et al.*, Mercier *et al.*, University of Michigan, Wang, Peek-Asa *et al.*, Li *et al.*).

Elderly drivers and occupants are especially at risk of thoracic region injuries due to increased bone fragility (University of Michigan, Wang *et al.*, Wang, Augenstein *et al.*, Foret-Bruno, Schiller, Sjogren *et al.*, Bulger *et al.*).

Results from S.C Wang, the head injury is the most frequent in younger age group, while the older age group is suffered from mostly thoracic injury as shown in Figure 10. From the NASS (1993-1996) data, the more old age group, the more numbers of rib fracture is occurred in the frontal collision.

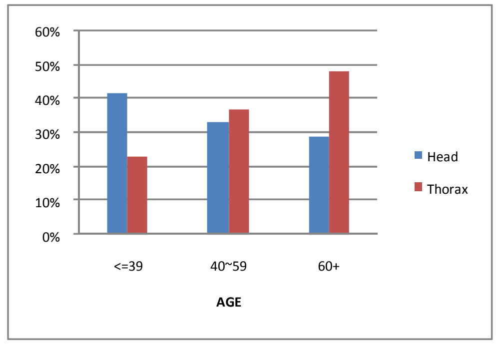

Figure 10. Incidence of Thoracic and Head Injury by Age Group. (S. C. Wang).

Korean Elderly Occupant Injury Patterns

From the Korea national accident database (2000-2007), the elderly occupants exposed higher risk in thorax, head and abdomen. The thoracic injury risk is 2.6 time higher than other age groups. The head injury is 1.3 time higher and abdomen injury is 1.9 time higher. The elderly male abdomen injury is 26.2% higher than that of female elderly occupant.

But, female elderly has higher potential risk in head and lower extremity 57% and 11.6% respectively more than those of male elderly. In seating position, driver side is 2.9 times more suffered thorax injury compared with 25 - 54 year old age group. Regardless the type of vehicles, the thorax injury of the elderly occupant is more than 1.7 - 2.1 times more frequently occurred.

The elderly seated in SUV and RV vehicles are more injured than sedan type vehicle during the car-to-car frontal collisions. The seat belted elderly is more suffered thorax, abdomen and upper extremity injuries than other age groups. However, compared with non belted occupants, there are no differences in terms of injury between different age groups. Even the airbag equipped vehicle, still elderly occupants exposed 12.9% more sever thorax injury compared with other age group.

2009 KNCAP FRONTAL CRASH TEST ANALYSIS

Ten vehicles from four Korean auto makers and two foreign auto makers were tested for KNCAP program in 2009. The test results and the star ratings for the vehicles are represented in Table 3.

Table 3. 2009 KNCAP Frontal Test Results

Vehicle	Class	Occupant	Full wrap Frontal Crash		Offset Frontal Crash	
			Star Rating	Probability of Injury	Star Rating	Points
Kia Soul	Sub-mid	Driver	★★★★★	8 %	★★★★★	15.1
		Passenger	★★★★★	9 %	★★★★★	14.4
Kia Forte	Sub-mid	Driver	★★★★★	9 %	★★★★★	14.2
		Passenger	★★★★★	9 %	★★★★★	14.1
GM Daewoo Lacetti	Sub-mid	Driver	★★★★★	9 %	★★★★★	15.6
		Passenger	★★★★★	8 %	★★★★★	13.6
Hyundai Genesis Coupe	Medium	Driver	★★★★★	8 %	★★★★	12.1
		Passenger	★★★★★	10 %	★★★★★	14.8
Benz C200K	Medium	Driver	★★★★	19 %	★★★★★	13.9
		Passenger	★★★★	17 %	★★★★★	14.2
Honda Accord	Medium	Driver	★★★★★	8 %	★★★★★	15.2
		Passenger	★★★★★	6 %	★★★★★	15.7
Ssangyong Chairman W	Large	Driver	★★★★★	7 %	★★★★★	15.2
		Passenger	★★★★★	7 %	★★★★★	15.2
Hyundai Equus	Large	Driver	★★★★★	7 %	★★★★★	13.6
		Passenger	★★★★★	7 %	★★★★★	14.4
Kia Sorento	Large (SUV)	Driver	★★★★★	9 %	★★★★★	14.8
		Passenger	★★★★★	9 %	★★★★★	14.9
Hyundai Veracruz	Large (SUV)	Driver	★★★★★	10 %	★★★★★	13.8
		Passenger	★★★★★	7 %	★★★★★	14.0

The HIC, Chest g's and Chest compression are represented in Figure 11 - Figure 12. All vehicles scored 5 stars in driver and passenger except one imported vehicle which was not designed for the full wrap barrier test. In the offset barrier test, only one 2 door domestic vehicle's driver side was not achieved 5 stars. Compared with previous year's (1999-2008) results, the safety performances were dramatically improved.

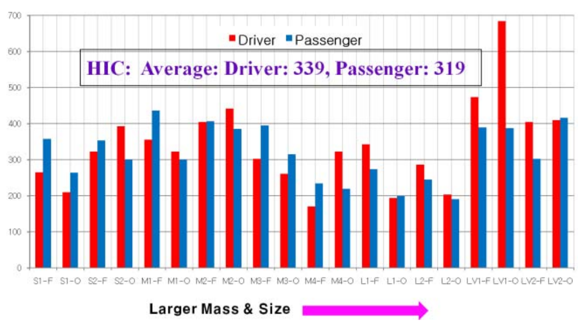

Figure 11. HIC Distribution of 2009 KNCAP

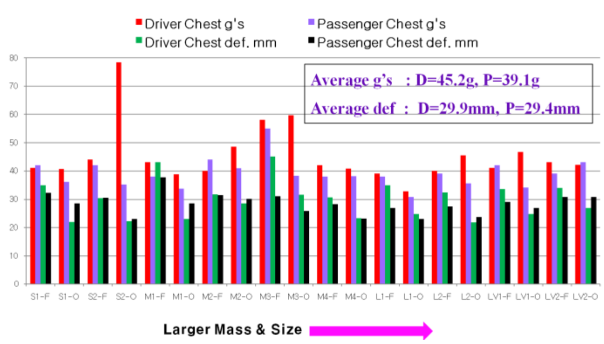

Figure 12. Chest Injury Distribution of 2009 KNCAP

From the dummy injury results, average of driver and passenger side HIC were 339 and 319 respectively. The 48km/h regulation required less than 1,000 HIC values. For the chest deflection case, while the 48km/h regulation required 76mm as a limit, but the average of chest deflection were 29.9mm and 29.4mm in driver and passenger side respectively. Even though more severe impact condition, the results shows a quite low chance of head and chest injury risks.

The next two Figures show the seatbelt loading forces measured in the Hybrid III 50%tile male dummy during the test.

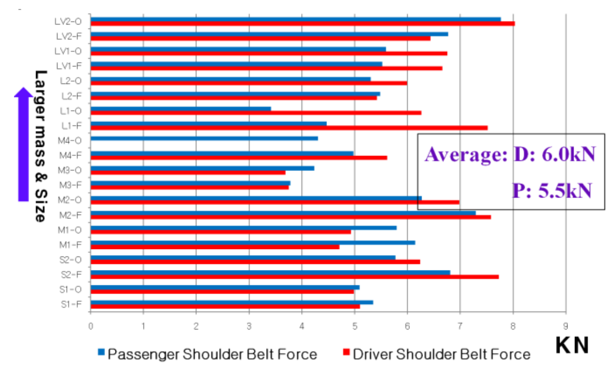

Figure 13. Shoulder Belt Forces of 2009 KNCAP

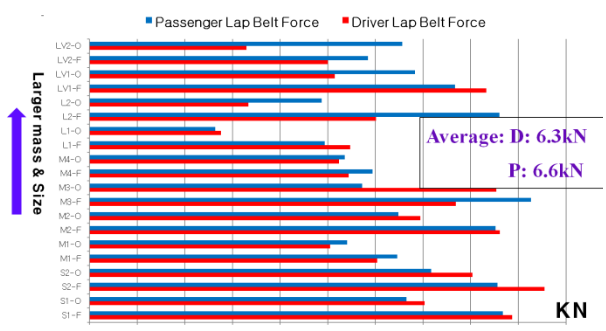

Figure 14. Lap Belt Forces of 2009 KNCAP

Results from Trosseille researches, the chest injury risk of AIS+3 for 40 year old occupants reveal less than 10% up to 6kN of shoulder belt force. However, the risk is dramatically increased. For the same level of shoulder belt force, 50 year old can be exposed 35% of risk and for 70 year old occupant, it can be reached up to 95% of AIS+3 thoracic injury.

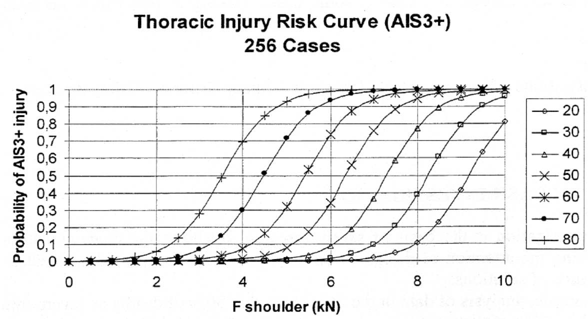

Figure 15. Probability of severe thoracic injuries (AIS3+) depending on the shoulder belt force and the occupant age (Trosseille)

Currently, the Hybrid III 50%tile male dummy is only one dummy regulatory body accepted. To protect elderly occupants from the thoracic injury during the frontal crash events, the further improvement of the chest deflection criteria is not sufficient enough without the controlling the stiffer seat belt force level.

PLANS FOR ELDERLY OCCUPANT THORCIS INJURY PROTECTIONS

The load limiter in the 3-point belt is intended to limit the forces exerted by the belt and thus the values for the thoracic load. Already in the early 1970 load limiters were applied in serial production, at that time, of course, without airbag. Their benefit has been demonstrated by accident analyses. Today load limiters are mostly applied in combination with an airbag to achieve an optimum alignment of the restraint system.

- Adoption of Modifier for Higher Belt Forces in KNCAP Rating System

From the 2009 KNCAP results, the average seatbelt force is about 6kN. From our researches and other previous researches, to protect elderly occupant from the thoracic injury, the load limiter should be in the range of 1.5 kN – 2.0 kN. Appling the modifier in the scoring system, this may lead the lowering seat belt force loadings as well as stimulating development of an adoptive restraint system as a universal design both beneficial for the standard size male occupant and the vulnerable occupants.

- Certification of 'Elderly Friendly Vehicle'

Now, in Korea, all applicable goods or productions can be achieved the unified Korea Certification (KC). The Korean government previously operated 170 certification systems. However, this excessive number of systems confused consumers and created an undue burden for companies in terms of time and expense. Consumers can choose products that comply with nationwide standards with regard to safety, health, quality and environmental impact.

Currently the requirement of 'Elderly Friendly Vehicle' for KC mark is investigated based on the research works.

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IIHS SIDE CRASH TEST RATINGS AND OCCUPANT DEATH RISK IN REAL-WORLD CRASHES

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ABSTRACT

Side impact crashes accounted for 27 percent of passenger vehicle occupant deaths in the United States in 2009. Although the fronts and rears of most passenger vehicles have substantial crumple zones, the sides have relatively little space to absorb impact forces or limit occupant compartment intrusion. Side airbags help to absorb impact forces and are highly effective in reducing driver death risk, but must work well with vehicle structures to maximize occupant protection. The Insurance Institute for Highway Safety (IIHS) has been evaluating passenger vehicle side crashworthiness since 2003. In the IIHS side crash test, a vehicle is impacted perpendicularly on the driver (left) side by a moving deformable barrier weighing 1,500 kg (3,300 lb) and traveling at 50 km/h (31 mi/h). Dimensions of the barrier, especially height, are designed to simulate the front of a typical SUV or pickup. Injury measures are taken from 5th percentile female test dummies in the driver and left rear seating positions, and injury ratings are computed for the head/neck, torso, and pelvis/leg based on biomechanical and crash research. Vehicles also are rated based on their ability to protect occupants' heads and resist occupant compartment intrusion. These component ratings are combined into an overall rating of good, acceptable, marginal, or poor. A driver-only rating was recalculated by omitting rear passenger dummy data.

To evaluate how well IIHS side crash test ratings predict real-world occupant death risk, data were extracted from the Fatality Analysis Reporting System (FARS) and National Automotive Sampling System/General Estimates System (NASS/GES) for years 2000-09. Analyses were restricted to vehicles with driver side airbags with head and torso protection as standard features. The risk of driver death was computed as the number of drivers killed (FARS) divided by the number involved (NASS/GES) in left side impacts and was modeled using logistic regression to estimate the effect of crash test rating while controlling for the effects of driver age and gender and vehicle type and curb weight. Death rates per million registered vehicle years were computed for all outboard occupants, and these were compared across the overall test rating for each vehicle.

Based on the driver-only rating, drivers of vehicles rated good were 70 percent less likely to die when involved in left side crashes than drivers of vehicles rated poor, after controlling for driver and vehicle factors. Driver death risk was 64 percent lower for vehicles rated acceptable compared with poor and 49 percent lower for vehicles rated marginal compared with poor. All three results were statistically significant. The vehicle registration-based results for drivers were similar, suggesting the benefit largely was due to crashworthiness improvements and not to differences in crash risk. The same pattern of results held for outboard occupants in nearside crashes per million registered vehicle years and, with the exception of marginal-rated vehicles, also held for other crash types. This suggests design changes that improved side crashworthiness also benefited occupants in other types of crashes. Among component ratings, the vehicle structure rating exhibited the strongest relationship with driver death risk. In sum, results show that IIHS side crash test ratings encourage designs that improve crash protection in meaningful ways beyond encouraging head protection side airbags, particularly by promoting vehicle structures that limit occupant compartment intrusion. Results further highlight the need for a strong occupant compartment and its influence in all types of crashes.

INTRODUCTION

The rate of passenger vehicle occupant deaths per registered vehicle has declined steadily during the past three decades among 1-3-year-old passenger vehicles [1], and this decline was similar when partitioned into front, side, rear, and single-vehicle rollover crash types. Side impacts accounted for 27 percent of the 23,437 people killed in passenger vehicles in 2009 [1].

Improvements in passenger vehicle crashworthiness have been an important factor in declining death rates [2], but protecting vehicle occupants in side impacts is especially challenging. Most passenger vehicles have substantial crumple zones in the front and rear, but the sides have relatively little space to absorb impact forces while limiting occupant compartment intrusion. Severe head and thoracic injuries are common and result from impacts with the intruding side structure or objects outside the vehicle [3]. Side airbags are designed to improve occupant protection by spreading impact forces over a larger area of an occupant's body and preventing an occupant from colliding with vehicle interior structures or objects outside the vehicle. Side airbags, particularly those that protect both head and torso, are highly effective in reducing driver death risk [4-6].

Side airbags and vehicle structures should work well individually and together to optimize occupant protection. Published since 2003, IIHS side crashworthiness ratings are based on this principle. In the IIHS side crash test, the subject vehicle is struck at a 90-degree angle on the driver side by a moving deformable barrier weighing 1,500 kg (3,300 lb) and traveling at 50 km/h (31 mi/h). Dimensions for the barrier, especially height, are designed to simulate the front of a typical SUV or pickup because side impacts by these vehicles types, compared with cars, result in higher death risk for occupants of the struck vehicles [7]. Injury measures are taken from 5th percentile female test dummies in the driver and left rear seating positions, and injury ratings are computed for the head/neck, torso, and pelvis/leg. Vehicles also are rated based on their ability to protect occupants' heads and resist occupant compartment intrusion. Head protection ratings for front and rear occupants are based on whether the dummies' heads are prevented from contacting the barrier and vehicle interior structures. The ability of the vehicle structure to maintain occupant compartment integrity is evaluated by measuring residual intrusion of the B-pillar. These component ratings are combined into an overall rating of good, acceptable, marginal, or poor [8].

Performance in the IIHS side crash test has improved since the program began in 2003, when only 17 percent of vehicles tested earned a good rating. By 2007, more than half of the vehicles tested earned a good rating, as did every vehicle tested in 2010. The current study evaluated the extent to which IIHS side crash test ratings are related to the risk of fatal injury in side crashes. The IIHS test was developed, in part, to encourage installation of side airbags with head protection, and manufacturers have responded by increasingly providing such airbags as standard equipment. The increased availability of head protection side airbags also was driven by other factors, including a commitment by automakers to install them as a countermeasure to the incompatibility between SUVs and passenger cars in side impacts [9] and, more recently, to federal side impact protection regulations that take effect in 2010 [10]. The IIHS test was intended to drive countermeasures in addition to head protection side airbags and to ensure side airbags worked with these other countermeasures to protect occupants in side impacts with taller passenger vehicles like SUVs and pickups. It is noteworthy in this regard that some vehicles with head protection side airbags have been rated poor in the IIHS test, although no vehicles have achieved a good rating without them. In the current study, vehicles with standard head and torso protection side airbags provide the baseline. The primary research question was the extent to which the IIHS side impact test captures improvement in side crash protection, beyond the protection offered by side airbags. This ignores some of the potential benefits achieved by the IIHS test, but results will be more applicable to the modern fleet, where side airbags are standard equipment in most new vehicles.

METHODS

Vehicles

Study vehicles were 1997-2009 model year passenger vehicles for which IIHS had developed side crash ratings and on which side airbags with head and torso protection were standard equipment. Vehicle nameplates with the same rating across model years were grouped together for analysis. For example, 2008-09 Ford Taurus models, which were rated good and shared the same component ratings for side crash protection, constituted one make/series/model year combination in the analysis. Of the 72 make/series/model year combinations, 43 were rated good, 14 acceptable, 7 marginal, and 8 poor.

Fatality Data

Counts of fatally injured occupants for each of the make/series/model year combinations were extracted from the Fatality Analysis Reporting System (FARS) for calendar years 2000-09. FARS is a census of fatal crashes on US public roads maintained by NHTSA. The make/series/model year combinations were identified from the 10-digit vehicle identification number (VIN) in FARS using VINDICATOR, a proprietary VIN-decoding program maintained by the Highway Loss Data Institute (HLDI), an affiliate of IIHS. Fatality counts for each make/series/model year combination were further categorized by occupant seating position (driver, right front, left rear, right rear), vehicle type (SUV/ pickup vs. car/minivan), curb weight, driver age (15-29, 30-64, 65+), driver gender, and initial point of impact (clock position). Information on vehicle type, curb weight, and side airbag availability were obtained from a HLDI database of vehicle features that can be associated with make/series/model year.

Vehicle Exposure Data

National vehicle registration counts for each of the make/series/model year combinations during 2000-09 were obtained from R.L. Polk and Company. Death rates per million registered vehicle years were computed for drivers and all outboard occupants for each make/series/model year combination. These rates normalize the fatalities in a particular make/series/model year combination by the number of vehicles on the road and frequently are used to assess differences in fatal crash risk among vehicles. However, vehicle exposure rates have some weaknesses. First, vehicle registration data do not provide information on registrants, and registrants may not be the drivers in crashes. This means that important factors such as driver age and gender cannot be controlled for in analysis. Second, vehicle exposure-based death rates can be affected by features related to crash likelihood as well as crashworthiness. Thus, for example, if vehicles with better side crash ratings also were more likely to have features such as electronic stability control, which is known to reduce fatal crash risk, then a vehicle exposure-based analysis mistakenly would attribute any effect to the rating. It usually is not possible to control for technologies like electronic stability control or other safety features because registration data are not sorted by these features.

Crash Exposure Data

Fatality rates per crash also were calculated for drivers involved in police-reported crashes using 2000-09 data from NHTSA's National Automotive Sampling System/General Estimates System (NASS/GES). NASS/GES is a nationally representative sample of about 50,000 crashes per year that can be weighted to produce national estimates (6 million police-reported crashes per year, on average, during the study years). The fatality rates per crash provided a means to remove the influence of factors that might affect crash likelihood.

As with FARS, vehicle make/series/model year can be decoded from the 10-digit VIN captured in NASS/GES. Driver age/gender and crash type also can be decoded, allowing these variables to be controlled for in analyses. A disadvantage of analyses using fatality rates per crash is that the number of crashes is an estimate, so the rates are more variable. Another disadvantage is that NASS/GES has limited or missing information on occupants other than the driver. As a result, the current analyses are limited to drivers.

Vehicle Ratings

Overall side crash test ratings of good, acceptable, marginal, and poor are intended to reflect the relative level of protection afforded to outboard occupants when struck by another vehicle on their side of the vehicle. The overall rating is derived from component ratings of vehicle structure (residual intrusion measured at the B-pillar), head contact protection for driver and left rear dummies, and injury risk measures from both dummies for the head/neck, torso (chest/abdomen), and pelvis/leg regions. The component ratings (good, acceptable, marginal, or poor) then are combined into the overall, published rating (see Appendix 1).

For analyses of driver fatality risk, injury measures and/or head contact protection ratings for the left rear dummy may not be meaningful. Therefore, an alternative rating was computed that omitted results applying only to the left rear occupant. This driver-only rating combines rating results for vehicle structure, driver head contact protection, and driver injury measures for the head/neck, torso, and pelvis/leg into a rating of good, acceptable, marginal, or poor based on the same cutoff values as for the overall rating [8]. The weighting system used to determine the two ratings is outlined in Appendix A. The driver-only rating is used by IIHS to evaluate side crashworthiness in vehicles without rear seating positions such as the Smart Fortwo.

Analyses

The primary analysis estimated driver fatality risk per left side crash exposure as a function of driver-only side crash rating because this is the most direct measure of improvement in crashworthiness associated with the rating. However, driver fatality risk per vehicle exposure also was examined, as was outboard occupant fatality risk per vehicle exposure, based on the overall side crash rating.

Logistic regression was used to estimate the percentage change in driver fatality risk in left side crashes associated with better driver ratings while controlling for vehicle type and curb weight and driver age and gender. Logistic regression also was used with individual components of the driver-only rating to assess their relative importance. Results are presented as odds ratios. Death is a relatively rare crash outcome (e.g., less than 10 percent in left side crashes), so odds ratios would be expected to closely approximate the corresponding risk ratios.

Because NASS/GES is a structured sample, conventional estimates of standard errors may underestimate the true values, resulting in a type-1 error rate higher than expected. Counts from NASS/GES were used in the denominator of the logistic regression model, and one method for obtaining more precise standard error estimates relies on subsampling the data [5]. However, this method would not work in the present study because of loss of degrees of freedom in some subsamples. Instead, a conservative type-1 error rate of 0.01 was chosen as the level of statistical significance.

RESULTS

Driver Death Rates by Overall Side Crash Rating

Table 1 lists results of two analyses of driver deaths in left side impacts by overall IIHS side crash test rating. The first tabulates driver deaths per million registered vehicle years by overall rating, which decreased monotonically with better ratings. Vehicles with an overall rating of poor had the highest driver death rate per registered vehicle year (15.53), and the rate was reduced by about a third with each higher rating. Vehicles with an overall rating of good had a driver death rate for left side crashes (4.30) that was 72 percent lower than for poor-rated vehicles.

The second analysis presented in Table 1 tabulates driver deaths per 100,000 drivers involved in police-reported left side crashes by overall rating. Again, driver death risk was highest for poor-rated vehicles (277) and lowest for good-rated vehicles (91, about 67 percent lower), but the death rate did not decrease monotonically with the rating. Drivers of marginal-rated vehicles had a slightly lower death rate (126) than drivers of acceptable-rated vehicles (135).

Driver Death Rates by Driver-Only Side Crash Rating

Table 2 lists results for the same two analyses of driver deaths in left side crashes but using the driver-only side crash test rating instead of the overall rating. With regard to the distribution of driver deaths by rating, the driver-only rating system moved many poor-rated vehicles to marginal, compared with the overall rating system analyzed in Table 1. This had the effect of increasing the driver death rate, whether per million registered vehicle years or per 100,000 drivers involved in left side crashes, for both marginal- and poor-rated vehicles. As a result, the driver death rates calculated for either exposure measure decreased monotonically with the driver-only side crash rating. Moreover, the strength of the relationship between side crash rating and driver fatality risk appeared very similar whether measured per vehicle exposure or per crash exposure. For each measure of risk, each level of improvement from a poor rating reduced driver death risk in left side crashes by about

Table 1.
Left side impact crash experience of drivers by overall IIHS side crash test rating, 2000-09

Overall rating	Driver deaths	Registered vehicle years	Driver deaths per 1,000,000 registered vehicle years	Drivers in police-reported crashes (left)	Driver deaths per 100,000 left side crashes
Good	144	33,459,066	4.30	158,380	91
Acceptable	46	7,204,334	6.39	34,125	135
Marginal	32	3,338,153	9.59	25,343	126
Poor	135	8,690,693	15.53	48,704	277

Table 2.
Left side impact crash experience of drivers by driver-only IIHS side crash test rating, 2000-09

Driver-only rating	Driver deaths	Registered vehicle years	Driver deaths per 1,000,000 registered vehicle years	Drivers in police-reported crashes (left)	Driver deaths per 100,000 left side crashes
Good	150	34,452,019	4.35	163,657	92
Acceptable	44	6,462,959	6.81	32,390	136
Marginal	99	8,036,545	12.32	52,072	190
Poor	64	3,740,723	17.11	18,433	347

30-40 percent. For driver death risk per registered vehicle year, the reduction between poor- and good-rated vehicles was about 75 percent, whereas the reduction was about 73 percent for driver deaths per left side crash involvement.

Logistic Regression for Driver Deaths per Crash by Driver-Only Side Crash Rating

The relationships shown in Tables 1 and 2, although stable across the two measures of risk, could be affected by other variables related to crash risk or vulnerability in a crash. Tables 3 and 4 provide the age and gender distributions of drivers killed in driver side crashes by driver-only side crash test rating. The age of drivers killed in left side impacts was not distributed equally across driver-only rating. Specifically, fatally injured drivers of poor-rated vehicles tended to be younger compared with drivers of good-, acceptable-, and marginal-rated vehicles. Drivers of poor-rated vehicles also were slightly more likely to be female compared with drivers of other vehicles. Variation in the age and gender distributions suggests the need to account for these driver characteristics when assessing the relationship between vehicle ratings and driver death risk. Other factors also could be important. Drivers of SUVs and pickups may have an inherently lower risk of serious injury in left side crashes because their seating positions, on average, are higher off the ground and potentially further from direct load paths of striking vehicles. Also, although the IIHS test results are independent of vehicle mass, or weight, many left side impacts are not exactly like the IIHS test configuration, and mass could be important in some of these crashes.

Table 4.
Gender distribution (in percent) of drivers killed in left side impact crashes by driver-only IIHS side crash test rating, 2000-09

Driver-only	Drivers killed		Drivers involved	
rating	Male	Female	Male	Female
Good	59	41	47	53
Acceptable	57	43	49	51
Marginal	59	41	42	58
Poor	45	55	41	59

Table 5 lists results of several logistic regression models on the risk of driver fatality in a left side crash. Each column lists a model containing the covariates for which odds ratios are provided. The first column lists results of a model with the only predictor variable being the driver-only side crash test rating. The effects of this rating did not substantially change when controlling for driver age/gender, vehicle type/curb weight, or both driver and vehicle factors (columns 2-4). This indicates that these factors, while affecting side impact death risk, do not confound the observed association of side crash test rating and driver death risk. The effects of driver-only IIHS side crash test rating were statistically significant for all models. In the fourth column, with all covariates in the model, vehicles rated good, acceptable, and marginal all had significantly lower risk of driver death given a left side crash than vehicles rated poor. The pattern of odds ratios indicated a 49 percent reduction for vehicles rated marginal versus poor, a 30 percent reduction for vehicles rated acceptable versus marginal, and a 16 percent reduction for vehicles rated good versus acceptable. Compared with poor-rated vehicles, good-rated vehicles were estimated to have a 70 percent lower risk of driver death in a left side (struck side) crash.

Relationships of the individual components of the driver-only rating with real-world driver death risk were examined using the remaining logistic regression models in Table 5. When looked at singly (columns 5-8), the component ratings most strongly related to driver death risk were those for vehicle structure and driver torso (chest/abdomen) injury. Each of the individual components, with the exception of driver head/neck rating, had the highest driver fatality risk for poor-rated vehicles and the lowest risk for

Table 3.
Age distribution (in percent) of drivers killed in left side impact crashes by driver-only IIHS side crash test rating, 2000-09

Driver-only	Drivers killed				Drivers involved			
rating	15-19	20-39	40-64	65+	15-19	20-39	40-64	65+
Good	9	31	35	25	5	42	42	11
Acceptable	9	32	18	41	11	41	37	11
Marginal	8	35	38	18	13	41	36	11
Poor	12	31	39	17	10	48	31	11

Table 5.
Logistic regression analyses (odds ratios) of driver death risk in left side impact crashes, 2000-09

IIHS driver-only side crash test rating and sub-ratings	**Driver-only**	Good	0.242*	0.240*	0.294*	0.299*					
		Acceptable	0.328*	0.319*	0.364*	0.358*					
		Marginal	0.519*	0.520*	0.514*	0.510*					
		Poor	1	1	1	1					
	Structure	Good					0.217*				0.129*
		Acceptable					0.329*				0.178*
		Marginal					0.452*				0.235*
		Poor					1				1
	Driver head/neck	Good						2.110			3.802
		Acceptable						1			1
	Driver torso	Good							0.422*		0.767
		Acceptable							0.547*		1.105
		Marginal							0.450		0.806
		Poor							1		1
	Driver pelvis/leg	Good								0.457*	1.596
		Acceptable								0.820	2.009
		Marginal								0.676	1.990
		Poor								1	1
Age		65+		2.083*		2.120*	2.194*	2.241*	2.124*	2.130*	2.062*
		30-64		1		1	1	1	1	1	1
		15-29		1.103		1.040	1.009	1.097	1.086	1.038	1.056
Gender		Male		1.523*		1.566*	1.560*	1.543*	1.558*	1.553*	1.540*
		Female		1		1	1	1	1	1	1
Vehicle type		SUV/pickup			0.654	0.668	0.678	0.585	0.691	0.533	0.743
		Car/minivan			1	1	1	1	1	1	1
Curb weight		500-lb increase			0.855	0.816*	0.774*	0.699*	0.831*	0.822*	0.782*

*Effect statistically significant at 0.01 level.
Note: 25 driver deaths from Table 2 were excluded because their make/series/age/gender combinations did not occur in the denominator (drivers in police reported crashes).

good-rated vehicles. However, the effect of improved rating was not monotonic for the driver torso or pelvis/leg ratings. The vehicle structure rating had the most systematic relationship to driver fatality risk and was the only component with a statistically significant relationship in the model with all of the component ratings (column 9). In fact, controlling for the other component ratings appeared to increase the strength of the relationship between structure rating and driver death risk in left side crashes.

With study vehicles restricted to those with standard head and torso protection side airbags, only two vehicles did not receive a good rating for driver head/neck injury measures; they had an acceptable rating. This suggests the unexpected, and not statistically significant, result that a good head/neck rating was associated with a higher driver death risk than an acceptable rating is likely an anomaly of uncontrolled factors related to those two make/series/model year vehicle combinations.

In all regression models in Table 5 containing driver age and gender as covariates, drivers ages 30-64 had the lowest risk of death in left side impacts, followed by drivers ages 15-29 with a slightly higher death risk. Drivers 65 and older were about twice as likely to die in left side crashes as drivers ages 30-64. The risk of death for male drivers in these crashes was about 50 percent higher than that for female drivers.

SUV/pickup drivers had a substantially lower death risk than car/minivan drivers in left side impacts, though this was not statistically significant. Each 500-lb increase in curb weight was associated with substantial and statistically significant reductions in driver death risk in left side impacts.

Side Crash Test Rating and Fatality Risk for Other Occupants and Other Crash Types

Table 6 examines the relationship between side crash test rating and death risk for all outboard occupants. Because occupants other than the driver are included, the overall rating, rather than the driver-only rating, is used. This expands the registration-based analysis in Table 1 for drivers, but it also considers five impact types: in addition to those crashes where the initial impact is to the side nearest the occupant, farside, frontal, rear, and other crash deaths are tabulated.

Among outboard occupants killed in nearside crashes, the crash type most closely represented by the IIHS side crash test, the death rate per million registered vehicle years was 68 percent lower for occupants in vehicles rated good versus poor. This result was very close to the risk reduction estimated for drivers only (72 percent), and the pattern of risk reduction as overall rating improved also was similar for outboard occupants. The risk of death for outboard occupants was 35 percent lower for vehicles rated marginal versus poor, 32 percent lower for vehicles rated acceptable versus marginal, and 28 percent lower for vehicles rated good versus acceptable.

There also was evidence of fatality risk reduction for outboard occupants in other crash types. Although the relationship often was not monotonic, good-rated vehicles had lower fatality risk per million registered vehicle years than poor-rated vehicles in all crash types. The size of the benefit estimated ranged from a low of 53 percent for other crashes to a high of 65 percent for rear crashes.

DISCUSSION

Occupant protection in side crashes remains an important highway safety challenge. Side airbags, especially those that protect the head, were introduced to improve occupants' chances of survival in side impact crashes and have been shown to be greatly effective. Seventy-seven percent of 2010 passenger vehicle models were equipped with head and torso protection side airbags as standard equipment [11]. However, different airbag designs may respond differently to crash forces, which also would affect occupant death risk. Therefore, the current study investigated the real-world benefits of improved side crashworthiness, as measured by the IIHS side crash test, beyond the benefits of head and torso protection side airbags.

Results of the analyses confirm there is substantial benefit from better performance in the IIHS side crash test that goes beyond the addition of side airbags. Overall, the estimated reduction in fatality risk for vehicle drivers struck on the driver side was 70 percent, even after controlling for driver age and gender and vehicle type and curb weight. In other words, the risk of driver fatality was more than three times greater for vehicles rated poor for side crashworthiness than for vehicles rated good.

Although this estimate was derived from fatal crash risk per crash involvement, the pattern of results was quite similar for analyses of driver fatal crash risk per million registered vehicle years and for analyses of fatal crash risk to all outboard occupants when struck on their side of the vehicle. This indicates that the kinds of design changes introduced by automakers to improve performance in the IIHS side crash test are having large, real-world benefits in reduced injury in side crashes for most occupants.

Given that all of the study vehicles had side airbags, the primary benefit appears to derive from improvements in vehicle structural performance — that is, the

Table 6.
Outboard occupant deaths by crash type and overall IIHS side crash test rating, 2000-09

Overall rating	Outboard occupant deaths: Near side	Far side	Front	Rear	Other	Registered vehicle years	Outboard occupant deaths per 1,000,000 registered vehicle years: Near side	Far side	Front	Rear	Other
Good	240	139	791	63	297	33,459,066	7.17	4.15	23.64	1.88	8.88
Acceptable	72	45	244	13	92	7,204,334	9.99	6.25	33.87	1.80	12.77
Marginal	49	49	186	10	83	3,338,153	14.68	14.68	55.72	3.00	24.86
Poor	195	93	474	47	163	8,690,693	22.44	10.70	54.54	5.41	18.76

increased resistance of side structures to intrusion. Although ratings for both the torso and lower extremity injury measures from the test dummies were related to fatality risk, the vehicle structure rating was the only significant predictor of fatality risk when all of the side crash test component ratings were examined simultaneously. Thus, the effects of torso and lower extremity ratings on fatality risk appear to be an indirect result of better structural performance, which logically would result in better injury measures from the test dummies.

The centrality of structural improvements in the relationship between test ratings and real-world side crashes also may explain the surprisingly strong relationship between side crash ratings and protection in many other types of crashes (Table 6). Structural improvements — that is, design changes that increase occupant compartment integrity in crashes — are likely to be important in crash types other than those for which they are specifically designed.

Potential Limitations of Study

One limitation of the analyses is that the ways in which vehicles are driven, including annual mileage, may vary by crash test rating. For instance, if riskier drivers tend to drive poor-rated vehicles than good-rated ones, then the death rate for poor-rated vehicles may be artificially high. However, the similarity of results for vehicle and crash exposure rates indicates this likely was not an issue. In particular, death rates per crash eliminated much of the variation that would be expected from differences in driving styles, although there still is the possibility that drivers of poor-rated vehicles get into more serious side crashes. In a further effort to control for this possibility, the main analyses in the current study used driver age and gender as covariates. No confounding was observed, but driver age and gender do not entirely control for any differences in risk-taking propensities.

Another limitation of the analysis of individual component ratings is that no information was available in the crash databases on the location or type of specific injuries. For example, when evaluating the effect of the torso rating, it makes sense to look specifically at thoracic injuries. Because the outcome measure was death, the effect estimates for torso rating could not be attributed to a reduction in thoracic injuries. If data on specific injuries were available, it may have been possible to further disentangle the effects of various component ratings.

The finding that side crashworthiness ratings were related to occupant fatality risk in other types of crashes might suggest a limitation. It could be hypothesized that this general reduction in occupant death risk per vehicle exposure suggests other factors might be responsible for the observed reductions. However, the reductions in fatality risk by rating category generally were not as well ordered for other crash types as for nearside crashes, showing that the effects were not exactly parallel. In addition, as discussed above, the side crash death reductions appeared due primarily to increased resistance to intrusion, and increased structural strength can be expected to affect survival rates in many kinds of crashes, especially those involving multiple impacts. Finally, it also is noteworthy that the magnitude of the reduction in driver death risk estimated in this study is consistent with the serious injury risk observed for Volvo drivers with improvements in side crashworthiness [12].

In summary, results of the analyses indicate the IIHS side crashworthiness evaluation program encourages vehicle designs that offer real-world safety benefits to occupants. These benefits extend beyond the introduction of side airbags and are due in large part to the ability of vehicle structure to resist intrusion. Occupant compartment strength is widely recognized as a first principle of crashworthiness. Brumbelow et al. [13] and Brumbelow and Teoh [14] provided a direct example of this by showing that stronger roofs were associated with lower serious injury and death risk in single-vehicle rollover crashes. Occupant compartment strength, measured as the ability to resist intrusion in the IIHS side crash test, was the best predictor of driver mortality in driver-side crashes among component ratings of the IIHS test rating in the present study. This finding highlights the importance of occupant compartment strength and shows that dummy measures alone are not sufficient to predict side impact crashworthiness.

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APPENDIX A

Weighting of individual components for overall and driver-only IIHS side crash test ratings

Component		Rating: Good	Acceptable	Marginal	Poor
Vehicle structure		0	2	6	10
Driver	Head protection	0	2	4	10
	Head/neck	0	2	10	20*
	Torso	0	2	10	20*
	Pelvis/leg	0	2	6	10
			Driver total = *d*		
Passenger	Head protection	0	2	4	10
	Head/neck	0	2	10	20*
	Torso	0	2	10	20*
	Pelvis/leg	0	2	6	10
			Passenger total = *p*		
Overall rating cutoffs (*d*+*p*)		0-6	8-20	22-32	34+
Driver-only rating cutoffs (*d*)		0-6	8-20	22-32	34+

*Poor rating to the head/neck or torso body regions result in no better than marginal overall or driver-only rating.

COMPARISON OF BIORID INJURY CRITERIA BETWEEN DYNAMIC SLED TESTS AND VEHICLE CRASH TESTS

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ABSTRACT

The Insurance Institute for Highway Safety rates vehicle seat/head restraint designs as good, acceptable, marginal, or poor using a protocol by the Research Council for Automobile Repairs' International Insurance Whiplash Prevention Group (RCAR/ IIWPG). Studies of insurance neck injury claim rates for rear impact crashes show that vehicles with seats rated good have lower claim rates than vehicles with seats rated poor, but the relationship between acceptable/marginal ratings and claim rates is less clear.

To better understand the relationship between measured neck injury criteria and injury claim rates, a series of rear impact crash tests was conducted to determine the influence of crash pulse, as dictated by vehicle structure, on the performance of seat/head restraints. The role of head restraint adjustment also was examined by comparing BioRID responses in the driver position, with the restraint adjusted according to the RCAR/ IIWPG protocol, and in the front passenger position, with the restraint adjusted to its lowest position. In an attempt to match the severity of the RCAR/IIWPG crash pulse, vehicles were struck by a flat rigid barrier to create a velocity change of 16 km/h (10 mi/h).

Four small cars with rated seat/head restraints and varying real-world neck injury claim rates were selected. The 2006 Honda Civic and 2005 Chevrolet Cobalt both received good ratings in the RCAR/ IIWPG sled test, but the Civic had a relatively low neck injury claim rate compared with the Cobalt. The 2006 Saturn Ion and 2005 Ford Focus both received marginal ratings in the sled test, but the neck injury claim rate for the Ion was comparable with that for the good-rated Civic, and the Focus had the highest neck injury claim rate among the vehicles tested.

BioRID response ratings for the driver position matched the sled test ratings for the Cobalt and Focus but were one rating level lower for the Civic and Ion. BioRID response ratings for the passenger position were the same as those for the driver position for all vehicles except the Cobalt, which was one rating level lower. The findings suggest that changing the RCAR/ IIWPG protocol to include vehicle specific crash pulses and/or changing the restraint setup would not improve the relationship between seat/head restraint ratings and neck injury claim rates. Furthermore, examination of additional BioRID injury metrics not currently assessed under the protocol does not help explain real-world neck injury claim rates and does not support changing the current evaluation criteria. Additional research is needed to determine whether vehicle underride/override alters vehicle accelerations in a way that makes crash tests more predictive of neck injury claim risk in rear-end collisions.

INTRODUCTION

Whiplash describes a range of neck injuries related to the differential motion between a vehicle occupant's head and body. In 2007, an estimated 66 percent of all insurance claimants under bodily injury liability coverage and 57 percent under personal injury protection coverage reported minor neck injuries. For 43 and 34 percent of bodily injury liability and personal injury protection claims, respectively, neck sprains or strains were the most serious injuries reported. The cost of these claims is about $8.8 billion annually, which accounts for 25 percent of the total dollars paid for all crash injuries [1]. Whiplash injuries can occur in any crash but occur most often in rear-end collisions. There were more than 1.7 million police-reported rear-end collisions in the United States in 2009, and 26 percent of these resulted in injury [2]. Insurance claim data show that almost 20 percent of drivers in rear impact crashes claim to have neck injuries [3].

Since 2004, the Insurance Institute for Highway Safety (IIHS) has rated seats and head restraints based on a procedure developed by the Research Council for Automobile Repairs' International Insurance Whiplash Prevention Group (RCAR/IIPG) [4]. The two-stage procedure evaluates the ability of seats and head restraints to prevent neck injuries in rear impact crashes. First, head restraints must be located to support an occupant's head in a rear impact. Studies have shown that head restraints positioned close to an occupant's head and above the head's center of gravity can significantly reduce the risk of neck injury following a rear-end crash [5-7]. Seats/head restraints with good geometry then are subjected to a simulated

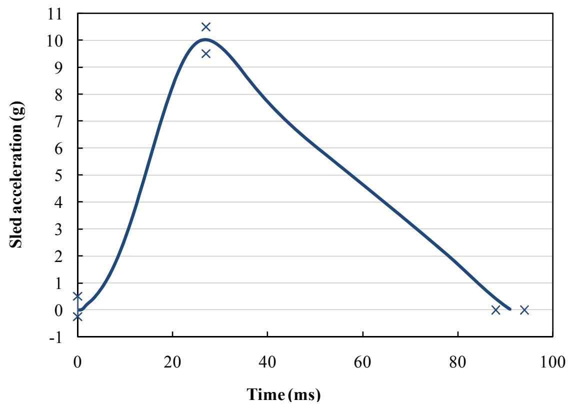

Figure 1. Target sled acceleration.

16 km/h rear impact using BioRID IIg [8]. All seats are tested with the same crash pulse, which is a simplified approximation of crash pulses from modern vehicles (Figure 1). Thus, the evaluation does not include the influence of a vehicle's rear structure.

Performance criteria for the dynamic test are divided into two groups: two seat design parameters and two dummy response parameters. The first seat design parameter, time to head restraint contact, requires that the head restraint or seatback contact an occupant's head early in the crash. This is to reduce the time during a rear crash that the head is unsupported by the restraint. The second seat design parameter, forward acceleration of the occupant's torso (T1 X acceleration), measures the extent to which the seat absorbs crash energy so that an occupant experiences lower forward acceleration. Seats with features that reduce contact time or have effective energy-absorbing characteristics have been shown to reduce neck injury risk in rear crashes [5].

The two dummy response parameters, upper neck shear force and upper neck tension force, ensure that earlier head contact or lower torso acceleration actually results in less stress on the neck. Measured neck forces are classified low, moderate, or high (Figure 2). To receive a good dynamic rating, a head restraint must pass at least one of the seat design parameters and also produce low neck forces. Table 1 lists ratings for other possible combinations of these criteria.

Research involving US insurance claim data has shown that vehicles with seat/head restraint designs rated good in the RCAR/IIWPG test have lower rates of whiplash injury claims than vehicles with seats rated poor [3], after controlling for other factors that influence neck injury claim rates (i.e., insurance laws in effect where the crash occurred, gender of seat occupant, body type of struck vehicle, cost of damage,

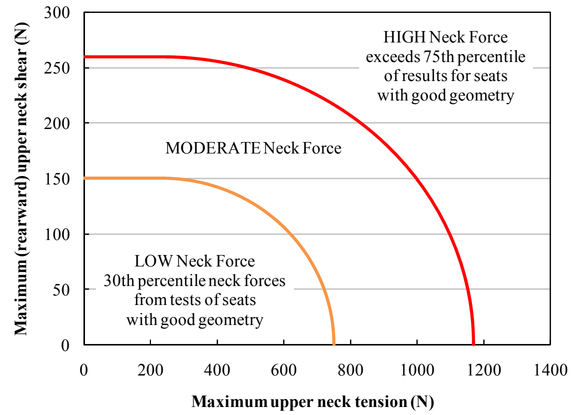

Figure 2. Neck force rating corridors.

Table 1
Dynamic rating requirements

Seat design criteria	Neck force classification	Dynamic rating
T1 X acceleration ≤9.5g OR Time to head restraint contact ≤70 ms	Low Moderate High	Good Acceptable Marginal
T1 X acceleration >9.5g AND Time to head restraint contact >70 ms	Low Moderate High	Acceptable Marginal Poor

and level of damage). Driver neck injury rates were 15 percent lower for vehicles with seats rated good than for vehicles with seats rated poor. Rates of driver neck injuries lasting 3 months or more were 35 percent lower for vehicles with seats rated good than for vehicles with seats rated poor. However, real-world neck injury rates associated with acceptable and marginal seats do not follow a linear trend as for rates associated with good and poor seats. Research involving Swedish insurance data has shown consistent findings [9]. One possible explanation for the lack of linearity is that vehicle characteristics not captured in the sled test are influencing real-world claim rates.

The objective of the current study was to determine whether vehicle-specific crash pulses could improve the relationship between seat ratings and real-world injury claim rates. A second objective was to investigate the effect of head restraint position on BioRID responses in full-vehicle rear impact tests. The RCAR/IIWPG protocol evaluates seats with their head restraints in the mid-height/mid-tilt position, but several studies have reported that adjustable head restraints often are left unadjusted [11-13]. Therefore, a comparison of injury measures between the RCAR/IIWPG head restraint position and the lowest restraint position may help explain the relationship between measured neck injury criteria and real-world injury claim rates.

METHODS

Driver neck injury rates were obtained from rear impact claims supplied by two automobile insurers. These claims, which were the same as those used to establish the relationship between injury ratings and real-world neck injury claim rates, were based on 2005-06 model year vehicles involved in rear impact crashes between January 1, 2005 and September 30, 2006 [3]. A total of 2,857 claims, when weighted by their sampling probabilities, were treated as being representative of 10,183 claims. Table 2 lists the injury rates by rating category with 95 percent confidence intervals and the range of estimates for the individual vehicle models in each group. The main finding was apparent that injury rates were lower, on average, for vehicles with seats rated good than for vehicles with seats rated poor, but it also was clear that injury rates for individual models in each rating group varied considerably. Some of this variation was due to the influence of variables that ultimately were controlled for in regression analyses reported in Farmer et al. [3]. The premise of the current study was to ascertain whether two vehicle models with the same rating but different injury rates would be rated differently after taking vehicle-specific crash pulse or alternate head restraint positioning into account.

Four small cars with rated seat/head restraints and varying neck injury claims rates were selected for full-vehicle crash tests. The 2006 Honda Civic and 2005 Chevrolet Cobalt both received good ratings in the RCAR/IIWPG sled test, but the Civic had a low neck injury claim rate compared with the Cobalt. The 2006 Saturn Ion and 2005 Ford Focus both received marginal ratings in the sled test, but the Ion had a neck injury claim rate comparable with that for the good-rated Civic, whereas the Focus had the highest neck injury claim rate among the four vehicles. Table 3 lists injury rates, number of weighted claims, and IIHS dynamic ratings for the vehicles tested. Although the differences in injury rates were not statistically significant, it was expected the differences more likely were due to variations in vehicle crash pulse rather than variations associated with body type, size/weight, or market class, as these characteristics were similar among all four models chosen.

The four vehicles identified in the claims study were subjected to rear impact crash tests. BioRID IIg dummies were positioned in the driver and front passenger seats of each vehicle. The driver dummy was positioned based on the RCAR/IIWPG dynamic protocol with the head restraint in the test position [4]. The passenger dummy also was seated based on the RCAR protocol with the exception that the head restraint was adjusted to its lowest position. All BioRID setup measurements were similar between the sled tests and full-vehicle crash tests except for head restraint height (Appendix A). Because the vehicles had been driven for 4-5 years prior to testing, the heights of the head restraints were significantly taller relative to the dummy's head than the new seats tested on the sled, likely due to compression of the seat foam associated with use.

Table 2
Driver neck injury rates by IIHS rating

Rating	Injury rate	95% confidence interval	Range
Good	16.15	13.50, 18.81	3.9-70.5
Acceptable	21.11	17.71, 24.52	0-33.3
Marginal	17.73	14.66, 20.80	0-100
Poor	19.16	16.04, 22.28	0-38.0

Table 3.
Injury claim rates and IIHS dynamic ratings

Vehicle	Claims (weighted)	Injury rate	95% confidence interval	IIHS rating
Civic	179	14.59	7.82, 21.35	Good
Ion	139	16.92	16.40, 33.52	Marginal
Cobalt	163	24.96	2.52, 31.32	Good
Focus	160	26.58	9.16, 44.00	Marginal

Table 4.
Mass of striking and struck vehicles

Vehicle	Mass (kg)
IIHS crash cart	1,479
2005 Ford Focus	1,462
2006 Honda Civic	1,451
2005 Saturn Ion	1,496
2005 Chevrolet Cobalt	1,498

After dummy positioning, each vehicle was struck in the rear by the IIHS side impact crash cart [14]. To eliminate any influence of underride/override, the deformable aluminum element was not attached to the barrier, resulting in a flat rigid impactor surface. In an attempt to match the severity of the RCAR/IIWPG crash pulse, vehicles were impacted to create a change in velocity (delta V) of 16 km/h (10 mi/h). Because the mass of the IIHS crash cart and test vehicles were very similar (Table 4), an impact speed of 32 km/h was chosen. The brakes on the struck vehicles were applied to simulate a stopped vehicle. BioRID injury criteria for the driver and passenger positions were evaluated to determine the RCAR/IIWPG rating.

The EuroNCAP whiplash assessment is based on results from three tests with different sled accelerations, one of which is the same as the RCAR/IIWPG crash pulse. The assessment includes three criteria — neck injury criterion (NIC), Nkm, and head rebound velocity — in addition to criteria used by RCAR/IIWPG. The relationship between these criteria and real-world injury claim rates also was examined [15].

RESULTS

In all four crash tests, peak vehicle accelerations were higher than the RCAR/IIWPG crash pulse (Figure 3). Vehicle accelerations also ramped up more quickly and delta Vs were higher than the RCAR/IIWPG target pulse. The RCAR/IIWPG protocol specifies a delta V between 14.8 and 16.2 km/h, whereas the crash tests produced delta Vs ranging from 18 to 19 km/h (Figure 4). Vehicle acceleration for the Saturn Ion was significantly different from those for the other vehicles. The Ion's peak acceleration was lower and occurred much later than those for the other vehicles, and was even later than the RCAR target pulse. Despite its lower and later peak acceleration, the Ion had the highest average acceleration between impact and 91 ms and the largest delta V (Table 5).

Based on RCAR/IIWPG seat and injury measures, the driver dummy in one of the four vehicles was rated good. The driver dummy in the Chevrolet Cobalt had low neck forces (Figure 5) and passed the seat design criteria with an early head contact time (Figure 6). The driver dummy in the Honda Civic also had an early head contact time but, with moderate neck forces, would have been rated acceptable. The driver dummies in Ford Focus and Saturn Ion both failed the seat design criteria and had moderate and high neck force ratings, respectively, resulting in a marginal rating for the Focus and poor rating for the Ion. For all four vehicles, upper neck shear force increased in the full-vehicle crash test compared with the sled test. Upper neck tension decreased for all vehicles except the Ion. The T1 longitudinal (X) acceleration increased for three of the vehicles, which was expected based on increases in vehicle accelerations. The decrease in T1 X acceleration for the Focus may have resulted from greater seat back rotation. Following the test, the seat back had rotated 12 degrees rearward, which was 4 degrees farther rearward than the seat in the sled test. Head contact time for each of the vehicles occurred earlier in the full-vehicle crash test compared with the sled test, also as a result of increased delta V.

With head restraints in the lowest position, none of the passenger dummies would have received a good rating (Figures 7 and 8). Passenger dummies in the Cobalt

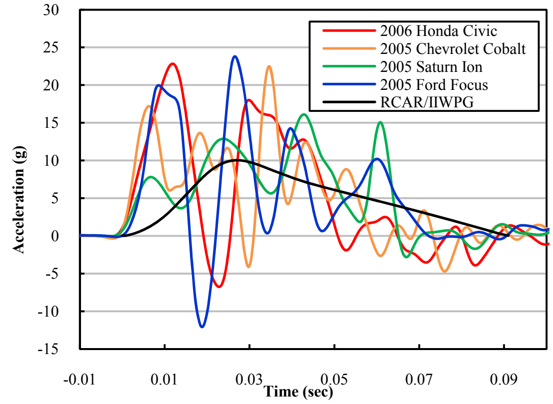

Figure 3. Longitudinal acceleration for vehicle crash tests.

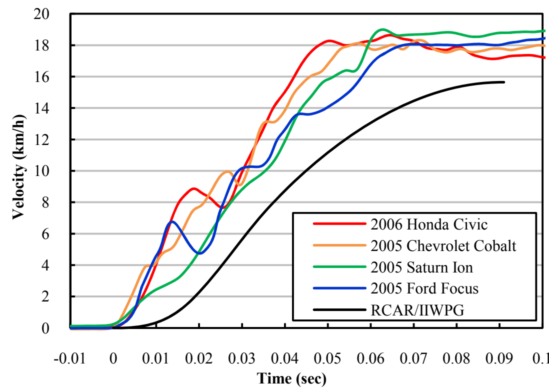

Figure 4. Change in velocity for vehicle crash tests.

Table 5. Vehicle acceleration characteristics

Vehicle	Peak accel. (g)	Delta V (km/h)	Average accel. (g)
2006 Honda Civic	22.8	18.6	5.34
2005 Chevrolet Cobalt	22.5	18.3	5.56
2005 Saturn Ion	16.1	19.0	5.78
2005 Ford Focus	23.8	18.1	5.61
IIWPG crash pulse	10.0	15.6	4.82

and Civic both were rated acceptable with early head contact times and moderate neck forces. The passenger dummy in the Focus would have been rated marginal by failing the seat design criteria and having moderate neck forces. The passenger dummy in the Ion would have received a poor rating by failing the seat design criteria and having high neck forces. For all passenger dummies, upper neck shear force decreased and upper neck tension increased compared with the driver dummies. T1 X acceleration and head contact time were similar between driver and passenger dummies. These results were consistent with differences between driver and passenger BioRID

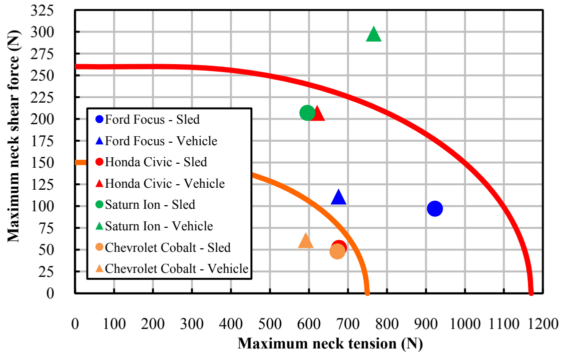

Figure 5. Neck force classification: sled vs. vehicle driver.

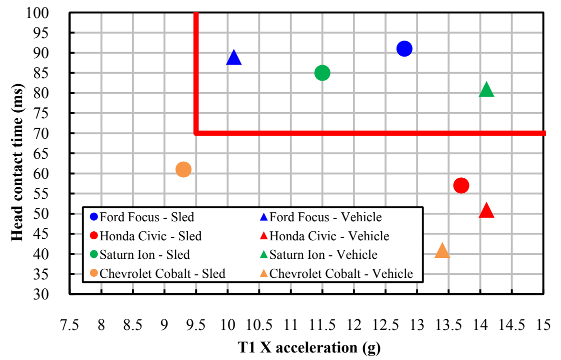

Figure 6. Seat design criteria: sled vs. vehicle driver.

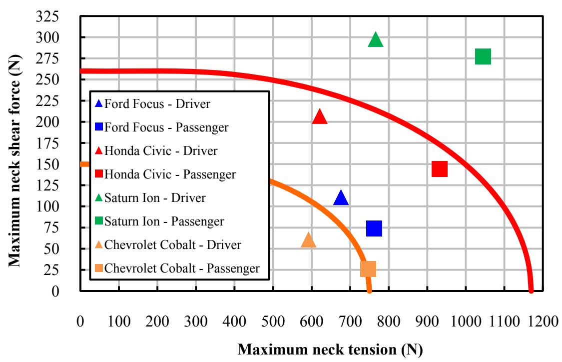

Figure 7. Neck force classification: driver vs. passenger.

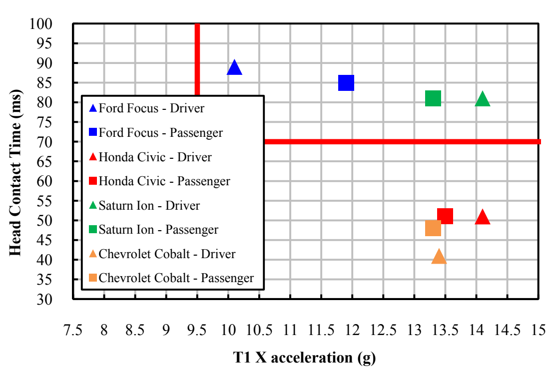

Figure 8. Seat design criteria: driver vs. passenger.

Table 6.
EuroNCAP criterion

Criterion	Performance Higher	Performance Lower	Capping limit
Neck injury criterion (NIC)	11.00	24.00	27.00
Maximum Nkm	0.15	0.55	0.69
Head rebound velocity (m/s)	3.2	4.8	5.2
Neck shear Fx (N)	30	190	290
Neck tension Fz (N)	360	750	900
T1 X acceleration (g)	9.30	13.10	15.55
Restraint contact time (ms)	57	82	92

setup measurements. In every case, BioRID backset was smaller for the passenger dummy compared with the driver dummy, whereas the height between the head and head restraint was significantly greater for the passenger dummy with the head restraint in the full-down position.

BioRID responses also were compared with neck injury metrics used in the EuroNCAP whiplash seat assessment (Table 6). Only the Ion had NIC values above the lower performance limit for EuroNCAP rating, with values for the driver and passenger dummies above the capping limit. The driver and passenger dummies in the Civic and passenger dummy in the Cobalt had maximum Nkm values above the capping limit. The driver and passenger dummies in the Ion and driver dummy in the Cobalt had maximum Nkm values above the lower performance limit. The driver and passenger dummies in the Focus had maximum NKm values between the lower and higher performance limits. The driver and passenger dummies in the Civic had head rebound velocities above the EuroNCAP capping limit, and the passenger dummy in the Ion had a head rebound velocity above the lower performance limit. Head rebound velocities for all other dummies were between the lower and higher performance limits. EuroNCAP results are contrary to real-world claim rates. The Civic and Ion had the lowest real-world claim rates but the highest dummy injury measures. The Cobalt and Focus had the lowest dummy injury measures but the highest real-world claim rates. Summaries of EuroNCAP injury metrics, NIC, maximum Nkm, and head rebound velocity, are shown in Figures 9-11.

EuroNCAP injury metrics were compared between sled tests and full-vehicle crash tests. Results indicated NIC values were higher for the Cobalt and Ion and lower for the Civic and Focus in full-vehicle tests. For all vehicles except the Focus, maximum Nkm values for driver dummies were higher in full-vehicle tests than in sled tests. For all vehicles, head rebound velocities for driver dummies were higher in full-vehicle tests than in sled tests.

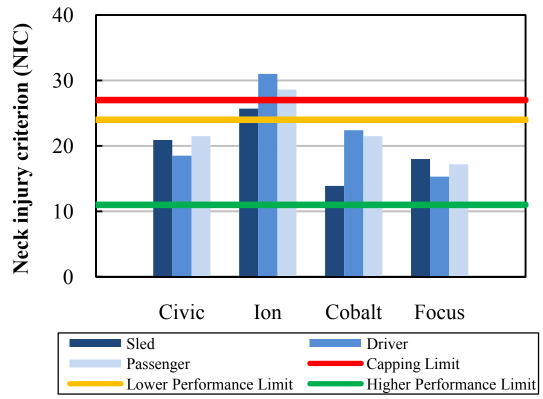

Figure 9. EuroNCAP results: neck injury criterion (NIC).

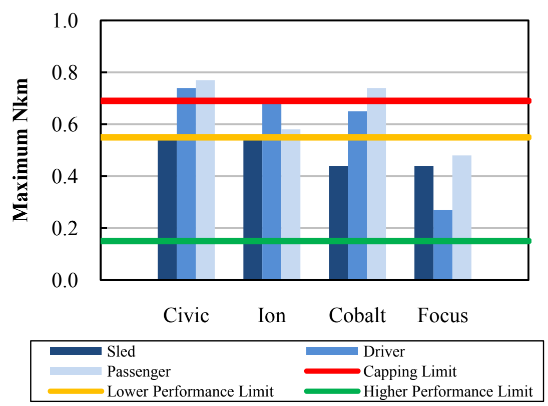

Figure 10. EuroNCAP results: maximum Nkm.

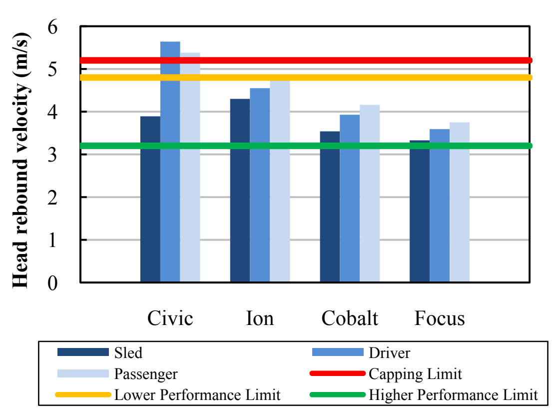

Figure 11. EuroNCAP results: head rebound velocity.

EuroNCAP injury measures were compared between the driver and passenger dummies. NIC values were higher for the passenger dummies in the Civic and Focus but lower for passenger dummies in the Cobalt and Ion. Maximum Nkm values also were higher for the passenger dummies in every vehicle except the Ion. For all vehicles except the Civic, head rebound velocities were higher for passenger dummies than for driver dummies.

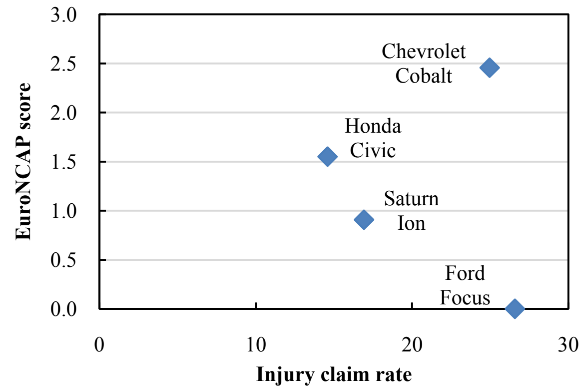

Figure 12. EuroNCAP scores for sled tests vs. injury claim rates.

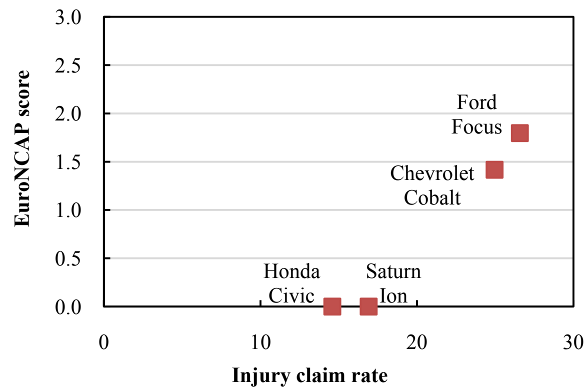

Figure 13. EuroNCAP score for driver dummies vs. injury claim rates.

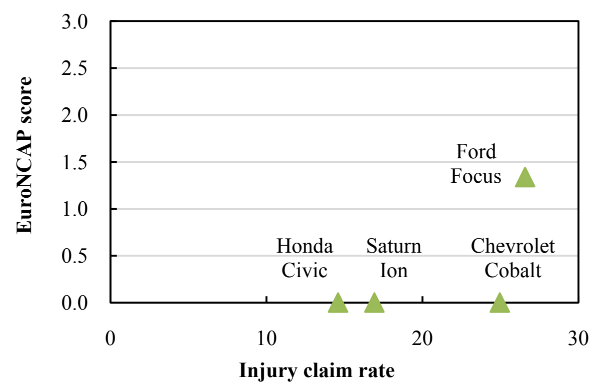

Figure 14. EuroNCAP score for passenger dummies vs. injury claim rates.

The EuroNCAP injury metrics failed to correlate with real-world injury claim rates for any of the three test conditions. In fact, dummy injury measures were lower for vehicles with higher real-world injury claim rates and higher for vehicles with lower real-world injury claims. Calculations of the EuroNCAP whiplash score (0-3) also showed no correlation to real-world injury claim rates for sled test results as well as results for driver and passenger dummies in full-vehicle tests (Figures 12-14).

DISCUSSION

The higher BioRID injury measures for the driver dummy in full-vehicle crash tests were consistent with higher vehicle accelerations compared with the RCAR/IIWPG crash pulse. This resulted in two seats being rated lower than in the sled test and two being rated the same. However, the vehicle-specific accelerations did not reorder the seat ratings based on these results in a way that was more consistent with real-world injury claim rates (Table 7).

Table 7
RCAR/IIWPG Ratings

Vehicle	Claim rate	Sled rating	Driver rating	Passenger rating
Civic	14.59	Good	Acceptable	Acceptable
Ion	16.92	Marginal	Poor	Poor
Cobalt	24.96	Good	Good	Acceptable
Focus	26.58	Marginal	Marginal	Marginal

Differences in injury measures observed between driver and passenger dummies in full-vehicle tests also were expected based on differences in BioRID setup measurements. The fact that upper neck shear force decreased and upper neck tension increased can be explained by the lower head restraint locations for passenger dummies. As with results for driver dummies, injury measures for passenger dummies in full-vehicle tests would yield lower ratings for the seats than ratings based on sled tests. However, these lower ratings were no better correlated with real-world injury claim rates than the sled test ratings. Furthermore, there is no combination of driver and passenger results that better correlates with real injury rates.

The vehicle-specific accelerations observed in this test series also do not explain the injury risk, but vehicle accelerations from flat barrier tests may not be representative of real-world rear impact accelerations. IIHS research has shown that some cars have a tendency to be underriden or overridden by striking vehicles [16]. Research by Thatcham shows that vehicle accelerations are significantly different depending on whether or not a vehicle's rear bumper system engages the striking vehicle's front bumper [17]. Vehicles with a tendency to be overridden or underriden tended to have lower vehicle accelerations. If the four vehicles in this test series had different override/underride tendencies, then it is possible that taking these tendencies into account would yield results different from those observed here.

CONCLUSIONS

Changing the RCAR/IIWPG protocol to include vehicle-specific crash pulses and/or changing restraint setup would not improve the relationship between seat/head restraint ratings and neck injury claim rates. Examination of additional BioRID injury metrics not currently assessed under the protocol does not help explain real-world neck injury claim rates and does not support changing the current evaluation criteria. Additional research is needed to determine whether vehicle underride/override alters vehicle accelerations in a way that makes crash tests more predictive of neck injury claim risk in rear-end collisions.

ACKNOWLEDGMENT

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APPENDIX A

Table A-1.
2006 Honda Civic BioRID setup measurements

Measurement	Sled	Driver	Passenger
Seatback angle (°)	13.9	14.2	14.3
Pelvic angle (°)	27.5	24.7	28.0
Backset, down (mm)	41.8	40.4	44.8
Height, down (mm)	100.6	86.7	81.4
Backset, up (mm)	56.7	55.4	60.1
Height, up (mm)	31.1	17.4	14.2
Backset, RCAR (mm)	51.6	50.9	55.6
Height, RCAR (mm)	57.5	44.6	39.0

Table A-2.
2005 Chevrolet Cobalt BioRID setup measurements

Measurement	Sled	Driver	Passenger
Seatback angle (°)	2.3	2.0	1.6
Pelvic angle (°)	27.2	24.7	25.7
Backset, down (mm)	36.1	42.5	43.9
Height, down (mm)	109.0	84.4	72.0
Backset, up (mm)	38.5	44.7	44.9
Height, up (mm)	51.6	24.2	13.0
Backset, RCAR (mm)	37.6	44.2	44.0
Height, RCAR (mm)	67.3	39.3	28.0

Table A-3.
2006 Saturn Ion BioRID setup measurements

Measurement	Sled	Driver	Passenger
Seatback angle (°)	10.7	8.6	9
Pelvic angle (°)	27.2	24.4	26.1
Backset, down (mm)	77.2	77.8	75.7
Height, down (mm)	118.5	96.7	105.1
Backset, up (mm)	89.6	87.7	87.6
Height, up (mm)	53.0	28.1	35.2
Backset, RCAR (mm)	84.9	84.2	82.6
Height, RCAR (mm)	78.5	51.7	61.8

Table A-4.
2005 Ford Focus BioRID setup measurements

Measurement	Sled	Driver	Passenger
Seatback angle (°)	14.8	14.5	14.2
Pelvic angle (°)	27.7	26.2	26.1
Backset, down (mm)	51.7	51.8	49.4
Height, down (mm)	104.6	81.7	78.7
Backset, up (mm)	68.9	68.8	68.1
Height, up (mm)	39.5	14.6	11.6
Backset, RCAR (mm)	58.7	58.9	57.4
Height, RCAR (mm)	78.2	54.6	50.9

APPENDIX B

Table B-1.
2005 Chevrolet Cobalt test results

Criteria	Sled	Driver	Passenger
Neck shear force (N)	48	61	26
Neck tension (N)	673	592	746
T1 X acceleration (g)	9.3	13.4	13.3
Head contact time (ms)	61	41	48
IIHS rating*	G	G	A
Neck injury criterion (NIC)	13.9	22.4	21.5
Head rebound velocity	3.54	3.93	4.16
Maximum Nkm	0.44	0.65	0.74

*G = good, A = acceptable, M = marginal, P = poor

Table B-2.
2006 Honda Civic test results

Criteria	Sled	Driver	Passenger
Neck shear force (N)	52	207	144
Neck tension (N)	677	621	932
T1 X acceleration (g)	13.7	14.1	13.5
Head contact time (ms)	57	51	51
IIHS rating*	G	A	A
Neck injury criterion (NIC)	20.9	18.5	20.5
Head rebound velocity	3.89	5.64	5.38
Maximum Nkm	0.55	0.74	0.77

*G = good, A = acceptable, M = marginal, P = poor

Table B-3.
2006 Saturn Ion test results

Criteria	Sled	Driver	Passenger
Neck shear force (N)	207	298	277
Neck tension (N)	596	766	1045
T1 X acceleration (g)	11.5	14.1	13.3
Head contact time (ms)	85	81	81
IIHS rating*	M	P	P
Neck injury criterion (NIC)	25.7	31.0	28.6
Head rebound velocity	4.3	4.55	4.85
Maximum Nkm	0.55	0.68	0.58

*G = good, A = acceptable, M = marginal, P = poor

Table B-4.
2005 Ford Focus test results

Criteria	Sled	Driver	Passenger
Neck shear force (N)	97	111	74
Neck tension (N)	923	676	762
T1 X acceleration (g)	12.8	10.1	11.9
Head contact time (ms)	91	89	85
IIHS rating*	M	M	M
Neck injury criterion (NIC)	18.0	15.3	17.2
Head rebound velocity	3.33	3.59	3.75
Maximum Nkm	0.44	0.27	0.48

*G = good, A = acceptable, M = marginal, P = poor

NHTSA'S TEST PROCEDURE EVALUATIONS FOR SMALL OVERLAP/OBLIQUE CRASHES

James Saunders
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Alpha Technology Associate, Inc.
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Paper Number: 11-0343

ABSTRACT

In September 2009, the National Highway Traffic Safety Administration (NHTSA) published a report that investigated the question "why, despite seat belt use, air bags, and the crashworthy structures of late-model vehicles, occupant fatalities continue to occur in frontal crashes." The report concluded that aside from a substantial proportion of these crashes that are just exceedingly severe, the primary cause was poor structural engagement between the vehicle and its collision partner: corner impacts, oblique crashes, impacts with narrow objects, and heavy vehicle underrides. By contrast, few if any of these the 122 fatal crashes examined in the report were full-frontal or offset-frontal impacts with good structural engagement, unless the crashes were of extreme severity or the occupants were exceptionally vulnerable. As a result of the NHTSA study, the agency stated its intent to further analyze small overlap and oblique frontal crashes in its Vehicle Safety Rulemaking & Research Priority Plan 2009-2011 published in November 2009 [NHTSA, 2009].

As part of the study the agency initiated a research program is to investigate crash test protocols that replicates real-world injury potentials in small overlap (SOI) and oblique frontal offset impacts (OI). The test program compared the results from vehicle-to-vehicle (VtV) tests to tests conducted with a moving deformable barrier-to-vehicle (MDBtV) and pole using the same baseline vehicles. The first part of the analysis of the results compared the vehicle crash metrics (pulse, change in velocity, and interior intrusion) of the MDBtV/Pole test procedure to the VtV test procedure. The second part of the analysis compared injury assessment of the MDBtV/Pole test procedure to the VtV test procedure.

INTRODUCTION

Previous research has been performed to define and study small overlap impacts (SOI). Lindquist et al. (2004) investigated 91 fatal frontal crashes in Sweden and found that SOI's, impacts with no longitudinal engagement, account for 48% of the fatalities of belted front row occupants in frontal collisions. Grosch et al. (1989) defined a partial overlap as a 20% overlap with no longitudinal engagement while Hill et al. (1993) defined a small overlap as one longitudinal engagement . Longitudinal engagement can be described as having part of the load path through a main longitudinal structural member or frame rail, with no longitudinal engagement referring to the load path missing both main longitudinal structural members (frame rails). Furthermore, Pintar et al. (2008) studied the National Automotive Sampling System – Crashworthiness Data System (NASS-CDS) and the Crash Injury Research and Engineering Network (CIREN) and concluded that trauma and injury pattern differed between small-offset and wider-offset crashes, and that countermeasures designed for wider-offset crashes may not be effective in small-offset crashes. Brumbelow et al. (2009) studied crashes that involved vehicles that were rated good for frontal crash protection. This study concluded that asymmetry in the loading of the vehicle will often cause intrusion into the occupant compartment leading to intrusion based injuries. Furthermore, this study stated that the most common crash modes leading to significant intrusion in frontal crashes are "asymmetric of concentrated loading across the vehicles front often resulted in occupant compartment intrusion and associated injury" and "small overlap, underride, and high-velocity moderate overlap crashes are the most common configurations producing substantial amounts of intrusion in frontal crashes." Kullgren et al. (1998) studied real world collisions and found that "the percentage of moderately and severely injured drivers was higher in impacts with an overlap below 30%." Sherwood et al. (2009) assessed the characteristics of "small-overlap" frontal crashes and concluded that "despite structural improvements prompted by offset crash tests, vehicle structures must improve if they are to prevent occupant compartment intrusion when a vehicle is loaded outboard of longitudinal structural members." Eichberger et al. (2007) investigated the accident statistics using GIDAS and Austrian databases and concluded that, in SOI, the longitudinal beams are not involved and the "rim locking effect" provides a load path into the occupant compartment, which endangers the safety cage. The rim locking effect is when two vehicle's wheels contact which drives the wheels back into the occupant compartment providing a load path to the toe pan and the side sill. This effect can be seen by any structure forcing the wheels rearward into the occupant compartment. The authors Eichberger et al. (2007) proposed a car-to-car test method to address the SOI scenario. This proposed test method was a 17% overlap collinear impact with a closing speed of 112 kmph. The intent of this test program is to develop a test protocol that replicates real-world injury potentials in SOI and oblique impacts (OI).

To develop a baseline understanding of vehicle interaction and occupant safety a series of vehicle-to-vehicle (VtV) test results were conducted and the results compared to a series of moving deformable barrier-to-vehicle (MDBtV) tests with the same vehicle. The first part of the analysis of the results compared the vehicle crash characteristics of the MDBtV/Pole to VtV. The details of each test procedure are described below. The second part compared measured occupant injury assessment of the MDBtV/Pole to VtV. The objective is to develop test procedures that replicate real-world crash conditions and injury outcomes such that a fleet study can be conducted.

VEHICLE CRASH CHARACTERISTICS

Vehicle Crash Metrics

The following is a list of vehicle crash metrics used to compare the target vehicle of the MDBtV test procedure to the target vehicle of the VtV test procedure. The first criterion is how well the acceleration pulses match (peak Gs, peak Gs timing, and duration). The second criterion is the velocity time history. The third criterion is the interior intrusion. The following are a list of interior intrusion measurements: four points across the middle of the toepan (row 2, Figure 1), the contact point where the left and where the right knee would hit the knee bolster in a full frontal test, the center of the steering wheel, the A-pillar. The A-pillar bottom intrusion was measured at the intersection of the top of the window sill and the A-pillar.

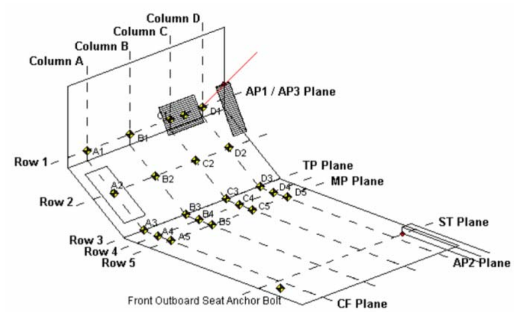

Figure 1: Toepan intrusion measurements points

Oblique Offset

Test Setup- Figure 2 shows the test setup for the VtV OI test procedure. The overlap is marked on the target vehicle (width excludes mirrors and door handles) and the stationary target vehicle is positioned at the desired angle. Once this is achieved, the outer edge of the bullet vehicle is aligned with the overlap mark on the target vehicle. The MDB OI setup is similar to the VtV OI setup except the edge of the honeycomb face is aligned with the overlap mark on the target vehicle (Figure 3). To achieve the same change in velocity (DV) for the target vehicle in the MDBtV OI test as in the VtV OI test, the closing speed was calculated using conservation of momentum.

A THOR-NT 50th percentile male test dummy was positioned in the driver's seat of all target vehicles in this study. The THOR-NT, as described by Shams et al. (2005), has advanced biofidelity and instrumentation features that were thought to be useful for the current study. From a biofidelity perspective, the THOR-NT has a more flexible spine and improved neck biofidelity compared to other 50th percentile dummies, allowing for kinematics that may better represent those of a human. The real-world analysis of the crash data (Bean et al., 2009) indicated that the occupant kinematics are a concern because of the oblique nature of the impact and it was thought that the improved flexibility of the THOR-NT's spine would better simulate the real world occupants motion. Among other instrumentation advantages of the THOR-NT, it has the capability of measuring multi-point (four locations) chest deflection and bi-lateral, tri-axial acetabular loads.

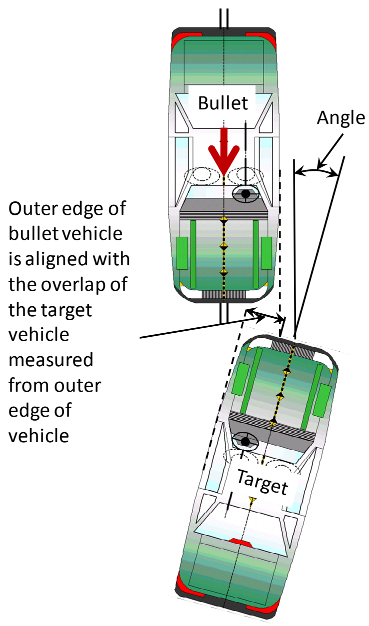

Figure 2: VtV OI test setup

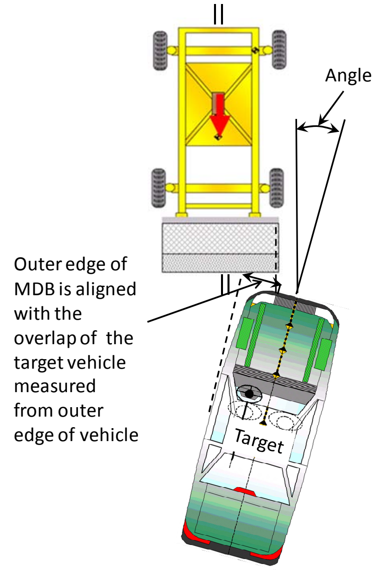

Figure 3: MDBtV OI test setup

<u>Results 214MDB OI-</u> The logical choice as a surrogate for the bullet vehicle in the VtV OI test procedure was the MDB specified in Federal Motor Vehicle Safety Standard (FMVSS) No. 214 (214MDB), since it is readily available. Computer simulations with the 214MDB in different test configurations were run with the Ford Taurus (model year vintage 2000-2006) to verify its suitability and the final test setup for the crash test. Based upon the VtV computer simulation results and comparing the results with real-world crash investigation data and damage patterns, a crash test delta-v (DV) of 35 mph and an overlap of 50 percent was selected.

Table 1 shows the test conditions for comparing the VtV OI test to the 214MDBtV OI test for the Ford Taurus and Ford Five Hundred (model year vintage 2005-2007). Figure 4 and Figure 5 show the x-axis accelerations for the left rear sill of the Ford Taurus and Ford Five Hundred, respectively. From these figures it can be seen that the acceleration has a spike early in the event, 40 ms for the Taurus and 25 ms for the Ford Five Hundred, for both vehicle comparisons. After that early spike in the acceleration the Taurus peak Gs and timing of the peak Gs are approximately the same, but the duration of pulse is shorter for the 214MDBtV OI test. For the Ford Five Hundred the acceleration was generally higher than the VtV OI acceleration up to the time peak Gs occurred. The peak Gs for the Ford Five Hundred occurred about

Table 1: Test matrix for oblique testing with the 214MDB

Vehicle / Mode	NHTSA Test No.	Bullet	Target	Closing Speed (kph)	Crabbed Angle (degrees)	Overlap (%)
Taurus Oblique	6830	2007 Taurus	2007 Taurus	113	15	50
	6852	214MDB	2007 Taurus	126	15	50
Ford Five Hundred Oblique	6831	2007 Five Hundred	2007 Five Hundred	113	15	50
	6937	214MDB	2007 Five Hundred	116	15	50

the same time, but was 10 Gs higher than the VtV OI test. The pulse duration was also shorter for the 214MDBtV OI Ford Five Hundred test.

Figure 6 and Figure 7 show the interior intrusion comparison of the 214MDBtV OI test and the VtV OI test for the Ford Taurus and Ford Five Hundred, respectively. The results present in the figure show that the toepan intrusions from the 214MDBtV OI matched the toepan intrusions of the VtV OI. However, the instrument panel and the A-pillar bottom intrusion did not correlate.

A number of issues were noted during the 214MDBtV OI tests. First, the front wheel of the 214MDB was damaged when it interacted with the target vehicle, since it was placed outside the face plate. Second, the 214MDB had the potential of bouncing down the track at these high speeds, since there was no suspension on the 214MDB. Finally, from film analysis it was observed that these spikes in vehicle acceleration early in the event for the 214MDBtV OI tests were caused by the 214MDB honeycomb bottoming out (at 40 ms for the Taurus and 25 ms for the Five Hundred) (Figure 4 and Figure 5). This anomaly was not detected in the computer simulations. Bottoming out during an MDBtV OI test procedure can represent the engine to engine contact, but these acceleration pulses are unrealistic and not representative of a VtV crash. With these results and the issue with the 214MDB, it was determined that modifications to the MDB design would be necessary to achieve results consistent with the VtV tests.

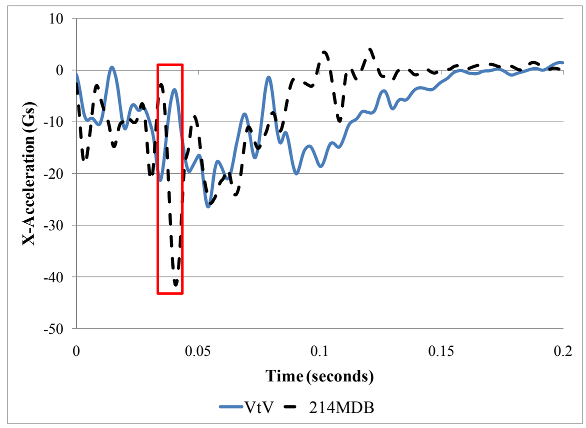

Figure 4: X-acceleration of the left rear sill for the target vehicle for the Taurus 214MDBtV OI comparisons

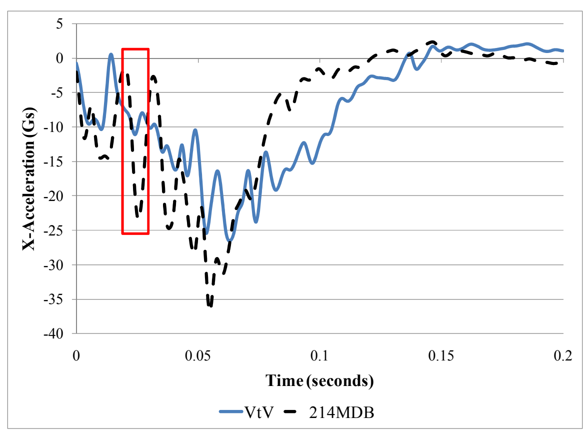

Figure 5: X-acceleration of the left rear sill for the target vehicle for the Ford Five Hundred 214MDBtV OI comparisons

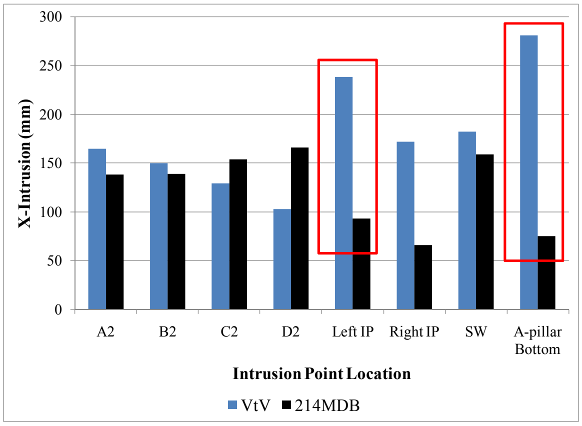

Figure 6: Interior intrusions for the target vehicle for the Taurus 214MDBtV OI comparisons

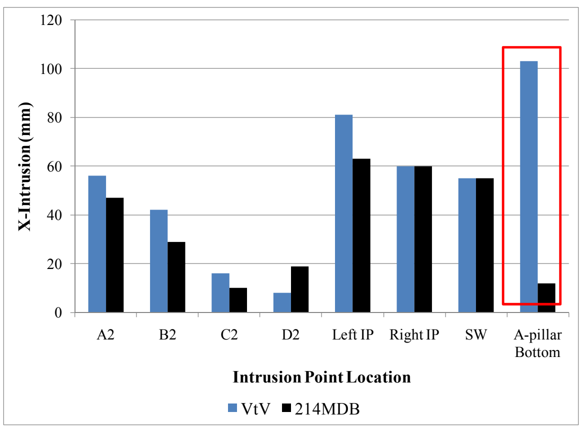

Figure 7: Interior intrusions for the target vehicle for the Ford Five Hundred 214MDBtV OI comparisons

<u>Results Research Moving Deformable Barrier (RMDB) OI-</u> To address some of the issues with using the 214MDB as a surrogate for the bullet vehicle, modifications were made to the MDB face and cart. This new barrier name is called "RMDB" throughout the rest of the paper. To prevent wheel damage, the barrier face plate was widened to be outside of the track width of the barrier. To minimize bouncing while traveling at high speeds, a suspension system was added to the cart. And finally, to prevent bottoming out of the barrier face too soon, finite element modeling of different barrier stiffnesses and thicknesses was performed. There was no attempt to match any certain vehicle characteristics in the design of the barrier (i.e. frontal stiffness) but only to address the issues raised in the previous series of tests. Figure 8 shows the RMDB final barrier face used as a surrogate for the bullet vehicle. To prevent a spike in the acceleration at the beginning of the test, a soft honeycomb was used in the front (0.724 MPa), and to prevent bottoming out, a second stiffer, honeycomb was added against the backing plate (1.71 MPa). The final weight of the RMDB was 2,385 kg.

The overlap used in the test setup was decreased from 50 percent (as used in the 214MDBtV tests) to 35 percent in an attempt to achieve A-pillar bottom and IP intrusions. It appeared since the MDB is homogenous the barrier more evenly distributed the crash load on the struck vehicle where an actual vehicle produced more localized loading due to the longitudinal frame rails. It was believed the change in overlap would allow the RMDB to interact more like an actual bullet vehicle as it could better expose the A-pillar and IP to more of the crash forces.

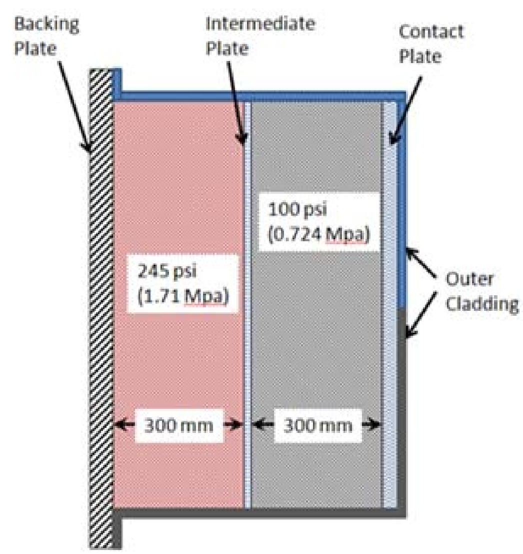

Figure 8: Final properties and thickness of the RMDB honeycomb face

Figure 9 show the x-acceleration of the Taurus in the RMDBtV OI test (NHTSA test number 7366). The general shape of the RMDBtV OI acceleration is similar to the VtV OI acceleration, except for the duration. The RMDBtV OI generally follows the VtV OI acceleration up to 40 ms and then the first peak in the acceleration is slightly higher and later in the event and the second peak is also slightly higher and later in the event. Figure 10 shows the RMDBtV

OI test had a steeper change in velocity than the VtV OI test and the RMDBtV OI test did not achieve the same total Delta V (DV) as the VtV OI test. Figure 11 shows that the toepan intrusions matched very well, but the instrument panel and the A-pillar bottom intrusion did not match.

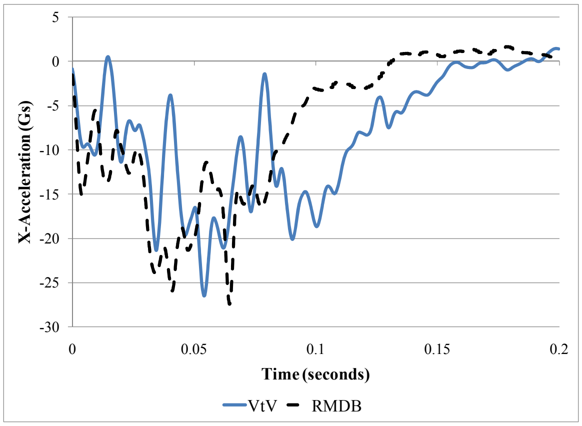

Figure 9: Left rear sill x-acceleration of the Taurus in the RMDBtV OI comparison

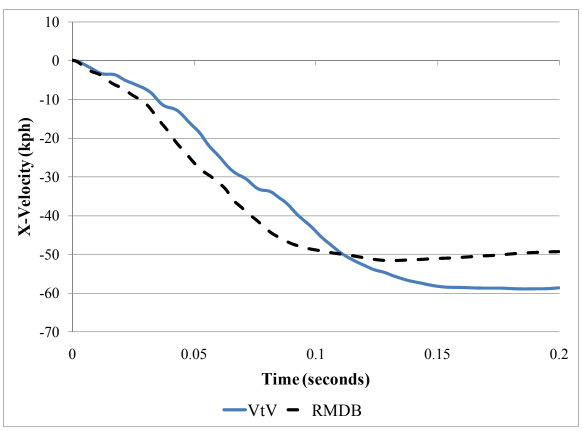

Figure 10: Left rear sill x-velocity of the Taurus in the RMDBtV OI comparison

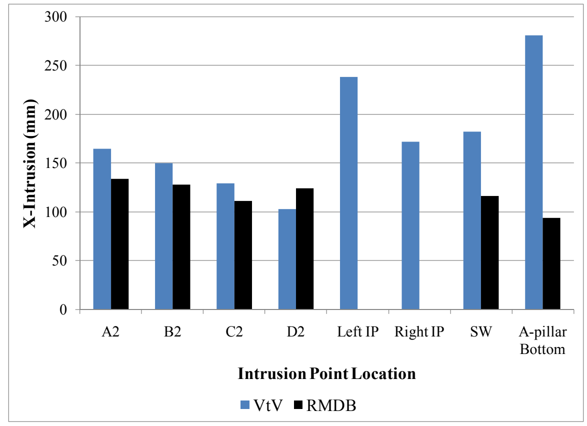

Figure 11: Interior intrusions for the target vehicle for the Taurus RMDBtV OI comparisons

Small Overlap

Test Setup- Some preliminary collinear pole crash tests were performed at the Medical College of Wisconsin (MCW). These tests showed that the vehicle started at the original offset and then pushed the vehicle laterally and the vehicle ended up sliding off the pole before it engaged the occupant compartment. The angle used in the OI procedure was used in the next set of tests, as a means to produce better engagement in attempt to achieve the intrusion levels observed in the field data. During these tests it was observed the pole did not tear down the side of the vehicle, but went toward the center of the vehicle. To keep engagement and the ability of the bullet vehicle to tear down the side of the target vehicle, an angle of 7 degrees was chosen for all SOI tests.

The VtV SOI test setup is the same as the VtV OI test setup described previously, with the exception of overlap. The overlap is determined by aligning the outside of the left longitudinal rail of the bullet and target vehicle (Figure 12). Again, the desired total DV of the target vehicle for the RMDBtV SOI test was calculated using conservation of momentum.

The second type of simplified test setup to represent the VtV SOI test is a target vehicle into a pole (VtPole SOI). In this setup the vehicle is positioned on a floating floor at the desired angle and then positioned such that the center of the tire is aligned with the edge of the 10 inch pole (Figure 13). The floating floor brings the target vehicle into the pole at the desired closing speed. Table 2 shows the test matrix for the SOI comparison of VtV SOI to RMDBtV SOI and VtP SOI tests.

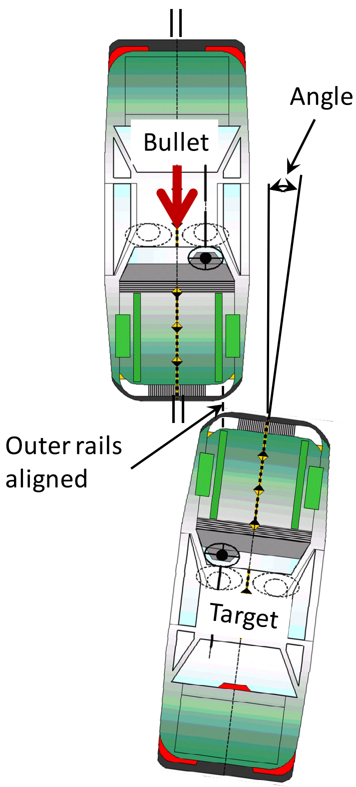

Figure 12: VtV SOI test setup

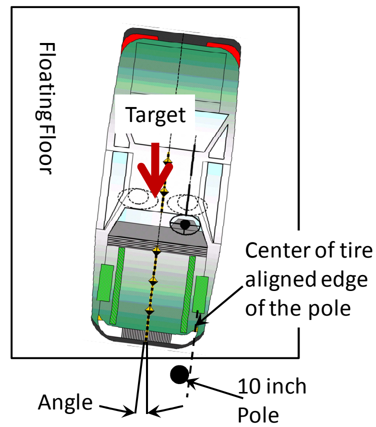

Figure 13: VtP SOI test setup

Table 2: Test matrix for small overlap tests

Vehicle / Mode	NHTSA Test No.	Bullet	Target	Closing Speed (kph)	Crabbed Angle (degrees)
	7292	2007 Taurus	2007 Taurus	113	7
Taurus SOI	7366	RMDB	2007 Taurus	97	7
	7144	10 inch Pole	2007 Taurus	56	7

1. Floating floor velocity

Results of RMDBtV and VtP SOI- Figure 14 shows the x-acceleration of the left rear sill of the target Taurus for the VtV SOI test procedure compared to the RMDBtV and VtP SOI test procedures. The acceleration pulse for the VtP SOI resulted in a lower peak Gs which occurred much later in the event than the other two test procedures. The RMDBtV SOI acceleration peaked about 10 ms before the VtV SOI test, but the peak Gs are similar in magnitude. The duration of the acceleration pulse is shorter than the VtV acceleration duration. Figure 15 shows the DV of the three test procedures. The VtP SOI shows the DV does not start to change until 50 ms and the total DV is slightly higher than the VtV SOI total DV. The RMDBtV SOI DV matched the VtV SOI DV up to 50 ms, then diverges resulting in a slightly lower total DV than the VtV SOI total DV.

Figure 16 shows the interior intrusion comparison of the VtV SOI test procedure to both the RMDBtV and VtP SOI test procedure. It should be noted that the IP intrusion for the RMDBtV SOI were not collected due to the IP separation. The VtP SOI test had higher IP intrusions than the VtV SOI test, but the toepan intrusions were lower. Also, the A-pillar bottom was lower for the VtP SOI test when compared to VtV SOI test. The RMDBtV SOI had more A-pillar bottom and SW intrusion.

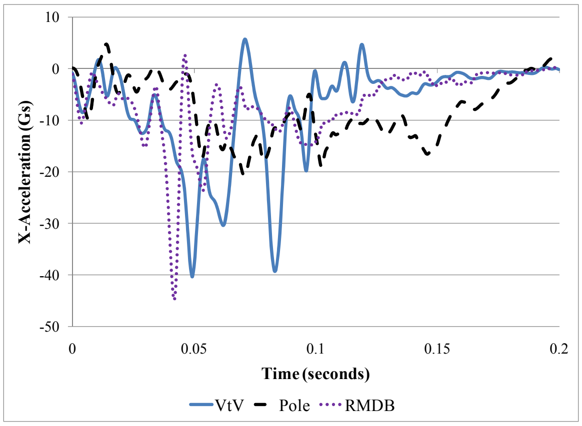

Figure 14: Left rear sill x-acceleration of the Taurus in the small overlap comparisons

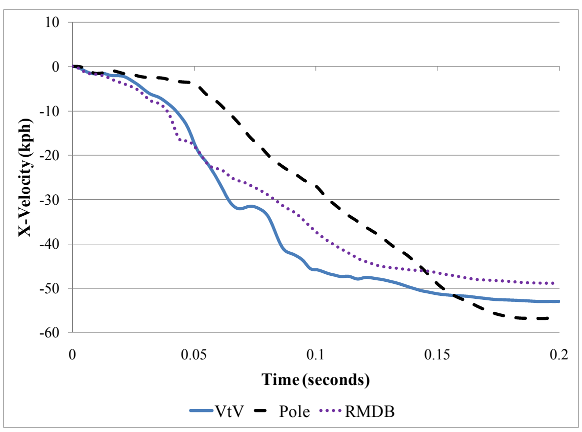

Figure 15: Left rear sill x-velocity of the Taurus in the small overlap comparisons

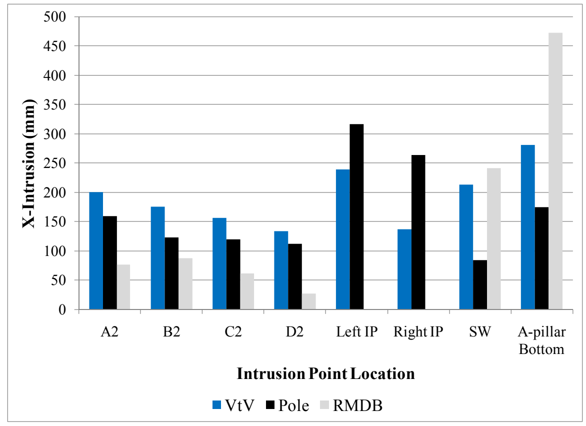

Figure 16: Interior intrusions for the target vehicle for the small overlap comparison

INJURY ASSESSMENT

In addition to the crash-based comparison metrics described earlier, the test results also were evaluated based on differences in anthropomorphic test device (ATD) kinematics and response. Table 3 summarizes the peak injury assessment values (IAVs) measured by the THOR-NT ATD in the driver's seat of the target vehicle for the Ford Taurus (model year vintage 2000 – 2006) and the Ford Five Hundred (model year vintage 2005-2007) tests. Many of the injury assessment reference values (IARVs) listed in Table 3 are provisional and are for reference only (i.e., final published versions have not been established). Others, such as those for the lower leg (Kuppa et al., 2001a,b), are more well established. The primary aim in this analysis was to compare the MDB and pole results to the baseline vehicle to vehicle results. The primary body regions that will be compared are head, chest, knee/thigh/hip, and lower leg. Three sets of comparisons are made: 1) Taurus oblique impacts (test numbers 6830, 6852 and 7366); 2) Five Hundred oblique impacts (test numbers 6831 and 6937); and 3) Taurus narrow overlap impacts (test numbers 7292, 7368 and 7144).

Table 3: Target vehicle driver THOR-NT 50th Injury Assessment Values

			Taurus - Oblique			Five Hundred - Oblique		Taurus - Narrow Overlap		
			50% Overlap Veh to Veh	50% Overlap 214 MDB to Veh	35% Overlap RMDB to Veh	50% Overlap Veh to Veh	50% Overlap 214 MDB to Veh	18% Overlap Veh to Veh	18% Overlap RMDB to Veh	Veh to Pole
Body Region	**Injury Metric**	**IARV**	NHTSA 6830	NHTSA 6852	NHTSA 7366	NHTSA 6831	NHTSA 6937	NHTSA 7292	NHTSA 7368	NHTSA 7144
			IAV	IAV	IAV	IAV	IAV	IAV	IAV	IAV
Head	BRIC	1	0.99	1.04	0.73	0.84	1.06	1.57	0.75	1.08
	HIC_{15}	700	594.0	233.6	290.1	363.0	576.0	216.7	504.5	535.3
	Resultant 3 ms clip (g)	80	89.2	49.6	53.0	59.4	74.5	47.9	78.8	90.3
Neck	Neck Tension (N)	2520	2767.2	1887.1	2311.3	1807.6	2157.0	2029.5	1287.6	1211.6
	Neck Compression (N)	3600	352.6	527.1	336.2	277.4	1215.7	234.6	713.8	254.8
	Flexion at OC (Nm)	48	18.0	6.2	23.1	21.1	4.3	15.1	12.8	17.5
	Extension at OC (Nm)	72	7.6	15.1	14.6	8.9	28.0	9.4	23.4	5.0
Chest	Upr Rt - Disp (mm)	NA[2]	30.4	33.5	35.8	41.7	44.4	IM[3]	27.9	31.6
	Upr Lt - Disp (mm)	NA[2]	17.7	15.5	20.2	23.7	31.6	8.9	9.1	8.0
	Lwr Rt - Disp (mm)	NA[2]	25.7	29.1	3.1	35.1	45.2	26.0	2.5	21.5
	Lwr Lt - Disp (mm)[1]	NA[2]	21.5	14.9	14.1	14.9	14.2	8.6	15.0	5.3
	Displacement Max (mm)	NA[2]	30.4	33.5	35.8	41.7	45.2	26.0	27.9	31.6
	3ms Chest Gs (g)	60	36.2	39.6	48.6	31.8	41.8	42.4	43.2	32.6
Abdomen	Displacement (mm)	111	37.0	31.3	38.2	43.7	36.4	29.0	24.6	33.1
Acetabulum	Rt Resultant Force (N)	3500	1267	3988	4474	1466	2060	2591	2794	2168
	Lt Resultant Force (N)	3500	6236	3650	4298	3376	1727	4184	5962	3169
Femur	Rt - Fz (N)	10000	3910	6768	7555	3472	4708	5167	4528	4148
	Lt - Fz (N)	10000	5755	6547	3538	4171	3091	6055	4805	4026
Tibia	Rt Upr Tibia Index	1.16	0.37	1.05	1.2	0.61	0.76	0.41	0.92	IM[3]
	Rt Lwr Tibia Index	1.16	0.59	1.37	1.41	0.87	0.51	0.37	0.69	IM[3]
	Lt Upr Tibia Index	1.16	0.45	0.44	1.34	0.33	0.58	0.56	3.19	IM[3]
	Lt Lwr Tibia Index	1.16	0.31	0.54	0.84	0.43	0.38	0.6	1.57	IM[3]
Ankle	Rt Inversion/Eversion	35 / 35	34.9	46.3	36.1	31.1	38.1	27.7	28.8	34.0
	Rt Dorsiflexion/Plantarflexion	35 / 35	40.4	36.7	45.2	34.3	32.5	17.9	31.7	11.6
	Lt Inversion/Eversion	35 / 35	16.4	30.9	IM[3]	23.7	25.7	7.6	IM[3]	30.2
	Lt Dorsiflexion/Plantarflexion	35 / 35	35.5	37.2	60.9	29.0	26.7	26.3	55.9	31.0

1. Shaded values represent points where deflection was positive (chest expansion)
2. There isn't currently a provisional IARV for chest deflection
3. Instrumentation malfunction

Head Injury Comparison

Comparisons to the VtV oblique and small overlap impacts start with an assessment of the head kinematics, contacts and injury measures. The three main injury measures summarized in Table 3 are BRIC, HIC_{15} and 3 ms peak acceleration. BRIC or brain injury criterion has been proposed by Takhounts et al. (2011) for the Hybrid III 50th, WorldSID and ES-2re test dummies. BRIC takes the peak head center of gravity (cg) rotational velocity and acceleration and divides them by their respective critical intercepts that were developed for the Hybrid III. The two numbers are then added. For the purposes of this study, it is assumed that the critical intercepts (46.4 rad/s and 39,477.9 rad/s2) for the THOR-NT are the same as the Hybrid III. The IARV of 1.0 represents a 30% probability of diffuse axonal injury (DAI).

Figure 17 shows the head CG resultant linear acceleration, rotational velocity time-history, and an image at the time of contact to the vehicle interior / door for the oblique Taurus tests. The head CG resultant acceleration shows a similar two-peak pattern in all three tests. The first peak occurs during head interaction with the air bag. The second peak results from head contact with the door frame or A-pillar. The Taurus to Taurus oblique test (6830) resulted in the THOR-NT ATD's head contacting the A-pillar/door frame. This contact produced the peak head CG resultant acceleration and HIC_{15} value for this test both of which were higher than the peaks observed in the Taurus MDBtV oblique tests. The two MDB tests (6852 and 7366) experienced steering wheel intrusion that, coupled with the occupant kinematics, resulted in greater shoulder and thorax interaction of the THOR-NT dummy with the steering wheel than what was observed in the vehicle to vehicle test. This steering wheel interaction limited the forward and outboard excursion observed in the VtV test. As a result, the peak head acceleration in both MDB tests occurred at roughly 70 ms during head interaction with the air bag, while the subsequent second peaks from head contact to door frame in both tests were smaller and were note within the HIC_{15} window.

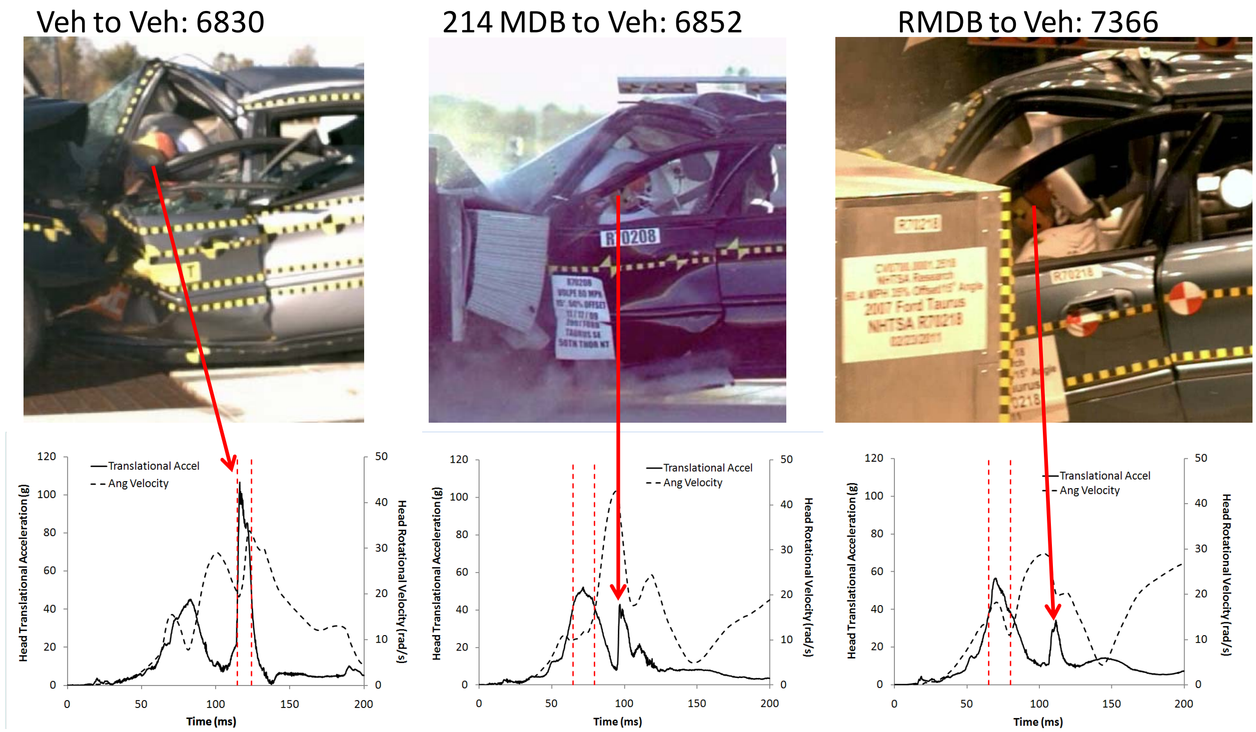

Figure 17: Head excursion for time history data for Taurus oblique tests (HIC_{15} time interval shown as vertical dashed lines)

Figure 18 shows the images and head response data for the oblique tests on the Ford Five Hundred. These tests had comparable kinematics, and did not have the same variable kinematics due to steering wheel interaction that was seen in the Taurus tests. The stiffer crash pulse in the 214MDBtV (Figure 4 and Figure 5) test resulted in higher peak translational acceleration and rotational velocity than the VtV test. Higher HIC_{15} and BRIC values were seen as a result. In the case of the VtV test, the THOR-NT ATD's head contacted the beltline, resulting in the peak translational acceleration. In the 214MDBtV test the ATD's head contacted its left lower arm, which was against the instrument panel at the time, resulting the peak acceleration.

Figure 19 shows a similar set of pictures and head response time histories for the Taurus SOI impacts. Each test again resulted in head contact to the vehicle interior/door. However, given the differences in pulse (Figure 9) and intrusion (Figure 11), the head contacts and resulting IAVs were significantly different between the three tests. The vehicle-to-vehicle test resulted in a head contact to the door frame. However, that contact did not contribute to the peak HIC value. HIC_{15} and resultant translational head acceleration in this test were the lowest of all eight tests summarized in this study. However, the peak rotational velocity and BRIC values were the highest of all eight vehicles studied. The RMDB (head contact to the a-pillar) and pole (head contact to steering wheel) had higher resultant accelerations due to their respective contacts, but rotation and thus

Chest Injury Comparison

The THOR-NT measures chest deflection in four locations that correspond to the anatomical 4th and 8th anatomical ribs. There is no provisional criterion in place for the use of the multipoint data. Separate research funded by NHTSA is slated to develop multi-point thoracic deflection injury criteria for the THOR-NT. Starting with the oblique tests of the Taurus (Table 3), it can be seen that the maximum chest deflection ranged from 30.4 mm in the vehicle

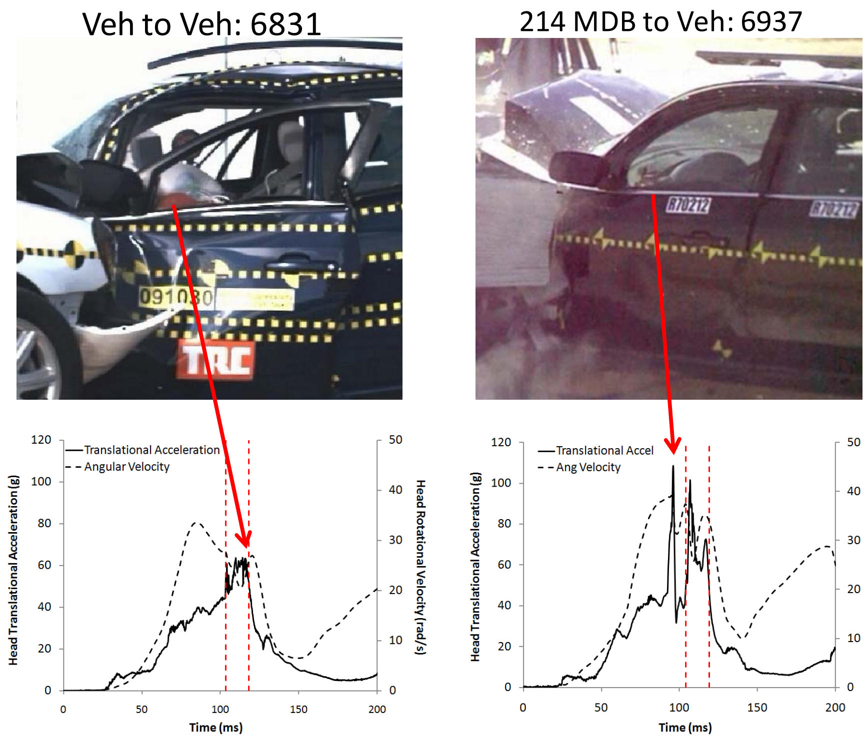

Figure 18: Head excursion and time history data for Five Hundred oblique tests (HIC_{15} time interval shown as vertical dashed lines)

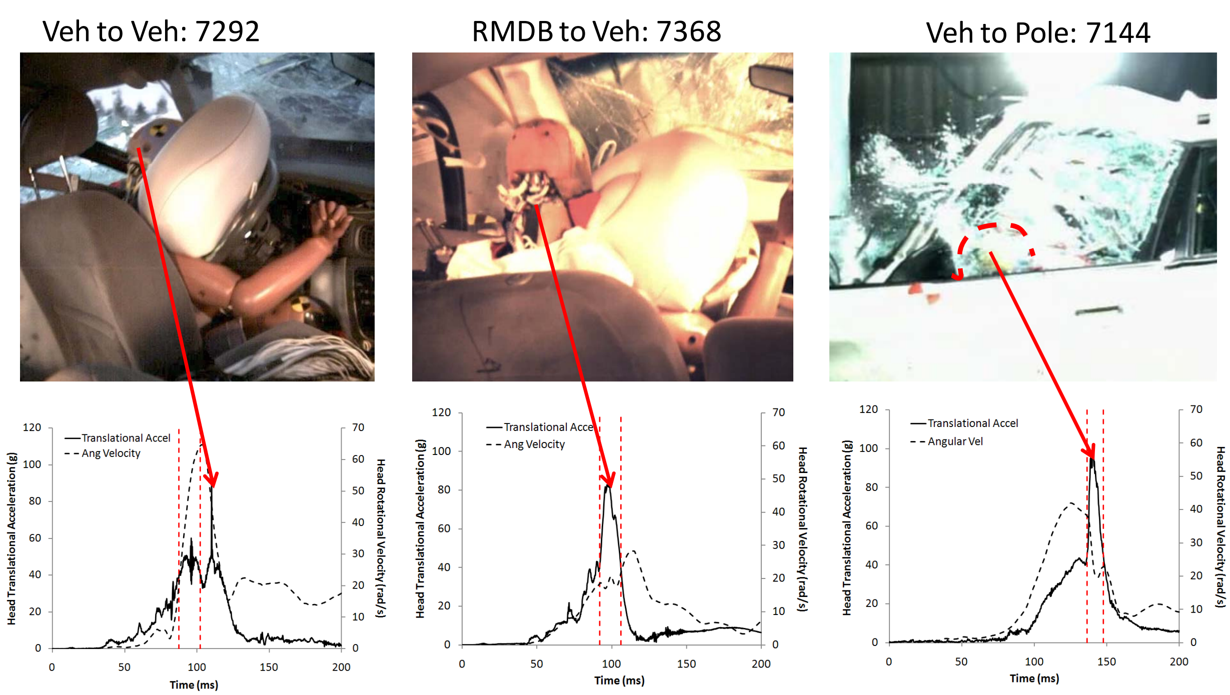

Figure 19: Head excursion and time history data for Taurus narrow overlap tests (HIC_{15} time interval shown as vertical dashed lines)

to vehicle test to 35.8 mm in the RMDB test. All peak deflections were measured at the upper right chest. While the differences in deflections were small, the associated peak shoulder belt loads did follow a typical trend where the case with lowest chest deflection had the lowest shoulder belt load (3.8 kN), while the case with the highest deflection had the highest shoulder belt load (5.3 kN). There was limited steering wheel interaction with the chest in any of these oblique tests on the Taurus. The oblique Five Hundred results showed comparable peak deflections for the VtV and 214MDBtV test. Similar to the oblique Taurus tests, there was limited interaction between the chest and the steering wheel.

It was not possible to compare the chest deflection results in the SOI tests due to an instrumentation malfunction related to the upper right THOR-NT chest deflection in the Taurus VtV SOI test (test no. 7292). The upper right chest deflection as documented in this study was typically the point of maximum deflection. However, in absence of valid upper right chest deflection data in the Taurus VtV test, it would be expected that the chest displacement measures in the SOI VtV test would have differed from those measured in the RMDBtV and VtP tests given differences in crash pulse and chest interaction with the steering wheel observed in the VtV test. While the VtV test did have a moderately stiffer pulse as compared to the RMDB test (Figure Figure 14), it was also notable as observed in analysis of the video that the THOR-NT in the VtV test had significant interaction with the steering wheel, while in the RMDB and pole tests of the Taurus there was limited or no interaction between the thorax and the steering wheel.

Knee / Thigh / Hip Comparison

Martin and Scarboro (2011) have looked at a selection of tests from NHTSA's frontal oblique / narrow overlap program. They have proposed a provisional IARV of 3,500 N for the resultant acetabular load. Looking at the three oblique Ford Taurus tests, it can be seen that all three tests exceeded the proposed IARV. However, the magnitudes and observed patterns differed from test to test. These differences, which are also notable in the differences seen in femur loads (especially when comparing the vehicle to vehicle test – 6830 and the RMDB to vehicle – 7366) are likely the product of differences in crash pulses and intrusions seen in these tests. It is noteworthy that none of the femur loads exceeded the 10 kN IARV in the oblique tests while all exceeded the provisional acetabulum load limit. In the Taurus SOI tests, right and left femur loads were highest in the VtV test, while the left acetabulum load was highest in the RMDB test. Differences in intrusion may have contributed to the measured differences in acetabular and femur loads between the VtV and RMDB tests. The pole test, which had more IP intrusion than the VtV test, had lower femur and acetabular loads. The softer crash pulse in the pole test (Figure 14) may have contributed to the lower loads.

Lower Leg Comparison

The lower leg IAVs in Table 3 include the respective upper and lower revised tibia indices and the ankle rotations for the right and left leg. Of the body regions evaluated, the results for the lower leg showed the greatest differences in performance in the MDB tests versus the VtV tests that they were designed to duplicate. All MDB or pole tests had at least one lower leg IAV that was at least 50% higher or lower than the corresponding value in the respective VtV tests. Differences in intrusion, initial foot/ankle placement, and crash pulse likely contributed to these highly variable values.

DISCUSSION

Vehicle Crash Characteristics

The change in the honeycomb from the 214MDB honeycomb to the RMDB honeycomb eliminated the high spike in the acceleration early in the event (Figure 20) and matched the pulse shape, but not the duration. The RMDB did not reproduce the desired DV and A-pillar bottom intrusion seen in the VtV OI test. This may be because the RMDB starts rotating sooner in the RMDBtV OI test than the VtV OI test, and part of the energy from the RMBD is released into the rotation of the barrier. This rotation may be caused by the center of gravity of the RMDB not being aligned with the vehicle center of gravity. The rotation may also be caused by the RMDB having no structure to stay engaged with the target vehicle.

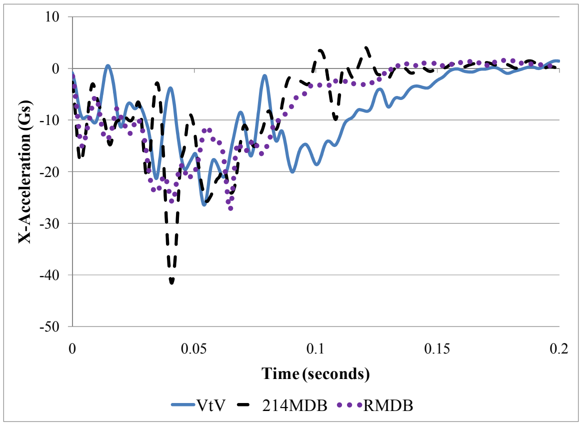

Figure 20: Comparison of x-acceleration of the left rear sill of the VtV OI test to the 214MDBtV and RMDBtV OI tests

The drop in the RMDBtV SOI acceleration and difference in the DV may be because of how the RMDB interacts with the vehicle during the test (Figure 15 (a) and (b)). As the RMDB moved down the side of the target vehicle and pushed the target vehicle wheel back into the occupant compartment, the RMDB started to ride up the tire, causing the barrier to override the vehicle and pushing the A-pillar back (see Figure 21). This was inconsistent with the baseline VtV test and likely explains the differences in the crash pulse and sharp drop off in the accelerations after the peak is reached.

Figure 21: Barrier override during Taurus SOI test

Injury Assessment

The main purpose of the IAV comparison in this paper was not to evaluate the IAVs against provisional IARVs, but as metrics for comparison of MDB and pole tests to the respective vehicle-to-vehicle tests in oblique and small overlap impacts. Simply looking at the peak values in Table 3 does not help one understand the source of those differences. The kinematics, head contact points, and thorax and lower extremity interactions were all dependent on vehicle crash characteristics, most notably the crash pulse and intrusion measures. For both the head and chest, it was observed in tests on the Taurus that steering column / wheel motion and intrusion affects both head and chest IAVs. It is possible that with more modern vehicles (the vintage Taurus evaluated in this study started in model year 2000), the motion and intrusion of the steering column will be more controlled. The two tests on the Five Hundred, which did not include the RMDB test at the time of this paper being submitted, had roughly 100 mm less steering wheel movement than the Taurus.

Current regulatory and consumer metric frontal crash evaluations with restrained occupants produce kinematics that result in sustained head interaction with the air bag and limited or no contact with interior components. The exception to this is the occasional bottoming-out of the ATD's head through the air bag to the steering wheel. The head kinematics and contacts described in this study span from the door, to the a-pillar and steering wheel. The oblique nature of the studied crash conditions, the limited overlap and other factors, such as steering column motion, affected the kinematics and resulting injury measures. As seen in the results of the current study, it is unreasonable to expect that a single MDB will be able to replicate the occupant response observed in a vehicle-to-vehicle test. Instead, it will be necessary to complete such paired analyses on multiple vehicles and vehicle types to see if the MDB can grossly replicate the occupant responses observed in vehicle to vehicle tests and at the very least the observed injury trends from real-world small overlap and oblique cases.

While it was not the paper's focus, it is notable to look at a few trends in IAVs versus IARVs for several body regions. First, concerning observed head injury measures, it is noteworthy that HIC_{15} values did not exceed the IARV of 700 in any test, while the rotational injury measure, BRIC, was exceeded in four of seven tests. The study of rotationally-induced brain injuries and associated injury metrics is an area of continuing study at NHTSA. While the use of BRIC or other rotational brain injury-related measures to assess occupant performance in crash testing is a relatively new concept, the results of this study do indicate a potential area for future emphasis regarding restraint system design. However, real-world analysis of crash data with respect to brain injury risk should be compared against the predicted risk based on BRIC prior to drawing broad assumptions related to its potential use in restraint system development. Finally, it was observed that none of the femur loads exceeded the 10 kN limit. However, in all of the tests on the Ford Taurus, the provisional acetabular resultant load IARV of 3,500 N was exceeded. While this may seem counter-intuitive, in studies of NASS-CDS and CIREN cases (Rudd et al., 2011), acetabular fractures are frequently observed in the absence of femur fractures.

The use of the THOR-NT in this research provides the opportunity for a more detailed look at the kinematics and injury measures that are appropriate for small overlap and oblique crashes. The advanced capabilities of the THOR-NT allow for injury risk evaluations that are not currently possible in other frontal ATDs. Most notably, the addition of multi-point thoracic deflection instrumentation provides the future opportunity to develop an advanced injury criteria. Also, as discussed by Martin and Scarboro (2011), the acetabular load measure presents an opportunity to study injury potential and countermeasures for addressing hip and pelvis fractures, which are prevalent in oblique and narrow overlap crashes.

LIMITATIONS

The RMDB developed for this test procedure was not designed to represent the exact characteristics of a vehicle, but to try to recreate the crash conditions (pulse, intrusion) that lead to injuries in oblique and small overlap crashes in the real-world. This paper only examines one vehicle (Taurus) for these different oblique and small overlap test procedures. The RMDB performance may be different for different classes of vehicles. Thus, it is not appropriate to draw conclusions from the evaluations of the RMDB on a single vehicle model.

Though it is interesting to compare the relative magnitudes and possible factors leading to the observed injury values within this test program, a future step will be to compare the predicted injury risk by body region and injury type in a more extensive set of fleet tests to the observed injury risks seen in field data.

CONCLUSIONS

Based upon the limited data, the following conclusions were made:

- The RMDBtV OI barrier face design prevented the spike in the acceleration early in the event due to bottoming out of the 214MDB and provided a similar acceleration pulse as the VtV OI test.

- The RMDBtV OI did not achieve the A-pillar bottom intrusion and total DV when compared to the VtV OI test.

- Vehicle-to-vehicle, MDB-to-vehicle and vehicle to pole tests, in their respective oblique conditions, produced head excursions that resulted in limited interaction with the driver air bag, allowing head contact with a variety of interior components. These observations are unique as compared to current belted consumer metric and regulatory frontal crash modes where ATD heads are generally well restrained by the air bag, but are consistent with case analysis of frontal oblique and narrow overlap real-world cases.

- Injury measures such as BRIC and resultant acetabular loads showed promise in being able to identify the potential for serious injuries that current instrumentation and/or injury measures may not have detected. While not available at the time of this study, it is expected that other advanced injury measures, such as a multi-point thoracic deflection injury criteria, could provide similar benefits.

- The THOR-NT has provided occupant kinematics and injury evaluation capabilities that will continue to assist in NHTSA’s efforts to develop and evaluate small overlap and oblique test procedures.

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DEFINITON OF A METHODOLOGY TO DEFINE A RISK INDEX FOR MOTORCYCLISTS ACCORDING TO THEIR EXPOSURE

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ABSTRACT

The casualty risk of drivers of having a road accident according to their exposure is usually defined by taking into account the frequency of use of the road infrastructure by these drivers. However, this information does not classify drivers according to their characteristics (age, sex, etc.), and does not enable effective measures for each driver profile to be adopted.

The objective of this project was to define a methodology to know the risk of having a fatal accident of a particular user driver group (professional drivers, car drivers, motorcyclists, etc.) according to their exposure to this risk, and according to different driver profiles within each group. An index was also defined, which can indicate this risk. In this study the methodology was applied to motorcyclist road accidents in Spain in 2007. Motorcyclists were classified into different profiles, considering not only the drivers' characteristics but also the type of motorbike they drove. This classification made it possible to discover which groups are more exposed to the risk of having a fatal accident, enabling prevention measures focused on these kinds of drivers to be adopted.

To perform this study a database was created, by merging an existing database which contained information about the victims and the motorbike they drove with another database which contained information about the mileage for each kind of motorbike. Following this the Index of Risk according to Exposure (IREx) for each profile was calculated.

The innovative aspects of this methodology are basically two: IREx assesses the risk by taking into account the mileage of the vehicle, and this assessment is performed separately for each profile of driver and type of motorcycle. The results of the study make it possible to observe some tendencies from which it is possible to draw conclusions which can be helpful in adopting measures to diminish the number of motorcyclist fatalities.

INTRODUCTION

Background

Our planet supports 6 billion people, more than 22m kilometers of roads, 470m passenger cars and 145m vans and trucks. A third of these vehicles travel on roads in the USA and another third in the European Union. According to the World Health Organization, an estimated 1.2m fatalities occur due to road accidents, while another 50m are wounded.

The modern European Union (27 countries) is home to 493m people and 270m registered motor vehicles. Each year there are 1.8m injuries, of varying severity, and 43,000 deaths in road accidents, a figure higher than the US (42,000) which however carries a significantly smaller population (290m) as well as a smaller fleet of vehicles (230m).

These road accidents are responsible for major economic losses, specifically accounting for 1% – 2% of a country's GNP. The European Council of Transport Security estimated the total cost of transport accidents to be about 166b€, 97% of which was related to road accidents.

In 2005, road fatalities of vehicle occupants amounted to 13,771 in the EU (of 14 member states). This represents 53% of deaths (all types) in that year. Of these 13,771 deaths, 9,419 were drivers and 4,349 passengers.

Road accident data from the CASE (Community database on Accidents on the Roads in Europe) database, indicate a high percentage of deaths and serious injuries on European roads, and have consequently led to years of observation, monitoring and acting upon the European citizen's road safety. A clear example is the goal set in 2001 by the European Commission, which aimed at a 50% reduction in road accident fatalities by 2010, a target set in the "European transport policy for 2010: Time to decide". Although the goal was not fully achieved, a significant decrease in fatalities was nevertheless noted (Figure 1). This is very positive, particularly if one takes into account the increasing number of vehicles on European roads annually and brings optimism to future road safety.

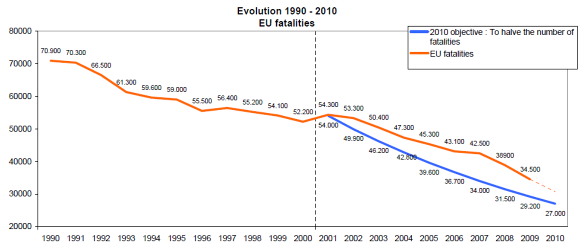

Figure 1. Evolution of road fatalities in the EU-25, 1990-2010 [Source: CARE (EU road accidents database)].

Both manufacturers and European states' governments are continually working to improve vehicle and road safety. The significant reduction of fatalities is largely due to two factors: technological progress of vehicle and infrastructure safety, as well as political measures adopted to improve road safetyand public awareness about road safety.

In Spain, the reduction of fatalities has been higher than the European Union average, coming in 2009 to a reduction of 53% compared to 2001 figures, surpassing the target set by the commission. This demonstrates the effectiveness of measures taken by the government in recent years, such as technological improvements and specific policies which have significantly improved vehicle and road safety and public awareness.

This decline in overall deaths however has not been reflected with the same intensity in **motorcyclists' fatalities**. While it is indeed true that since 2007 motorbikes related deaths have been reduced, previous years saw an increase (see Figure 2).

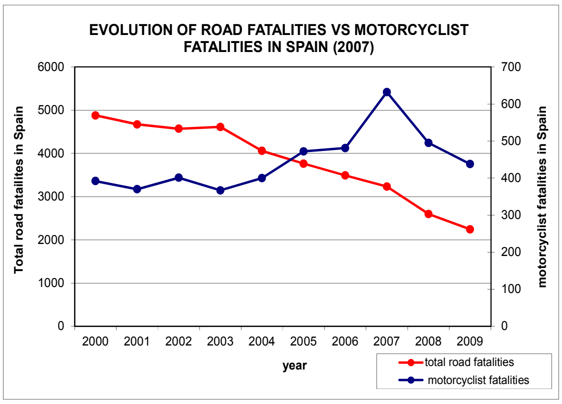

Figure 2. Comparison between absolute road accident fatalities and motorcyclist fatalities in Spain [Source: Statistical Yearbook of accidents (DGT)].

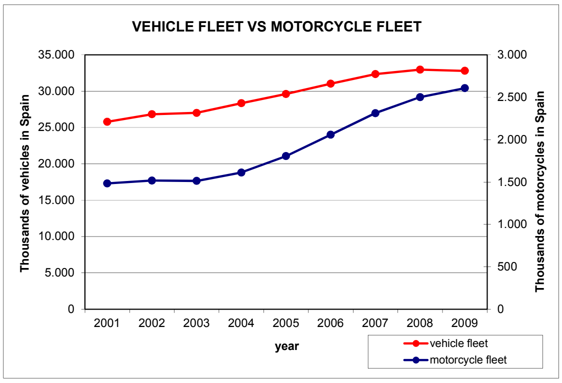

Figure 3. Comparison between vehicles and motorcycles fleets in Spain [Source: Series históricas. Anuario Estadístico General (DGT)].

Looking at Figure 3, it can be seen that over recent years there has been a significant increase in the number of vehicles and also motorcycles. However, in general vehicle accidents over the past decade have been constantly decreasing, whereas motorcycle accidents have been increasing along with the fleet, and only in the last few years has there been a significant decrease. Therefore, we can conclude that there is essentially no valid reason to justify the high number of motorcyclist accidents in the early years of 2000 due to the increase of the fleet of motorbikes.

Objectives

This paper presents a methodology **to determine the risk of suffering serious injuries or death** depending on the specific **exposure** of different groups of road users and average mileage travelled by each of them. In a road accident, the probability of having an (motorcycle) accident should be associated with accident data and the number of kilometers travelled by different groups of motorcyclists and motorcycles. Using the methodology outlined in this study, the several profiles of riders and motorcycles are reviewed, and the chance of them being involved in a road accident, regardless of its severity, can be evaluated.

An indicator was defined, to assess this risk of having a road accident for each group (type of motorcycle and/or engine type), based on accident data and mileage done by the different profile of driver, in other words their real exposure to this risk. Furthermore, this profile classification (by driver age, type of motorbike and engine power) allows us to identify which groups are exposed to more risks, i.e. demonstrating the influence of the profile of the driver and/or type of motorcycle in the overall accident statistics.

WORK METHODOLOGY

Definition of the different profiles

Before starting working with the provided data, the profiles in which the drivers (in this case riders and motorcycles) would be studied and divided had to be pre-defined.

For a number of reasons, an important one being climatic conditions, motorcycles are popular in all age ranges in Spain. The sample through the accidentology data went through the following classification:

- 18 to 24 years old
- 25 to 34 years old
- 35 to 44 years old
- Over 44 years old

In the case of the bikes, two different parameters were taken in consideration to classify them: type of motorcycle and engine displacement. Regarding the former, 8 different types were identified (Annex I, Figure 10):

- Sport
- Naked
- Scooter
- Touring
- Cruiser
- Trail
- Offroad
- Supermotard

Trail, Offroad and Supermotard motorbikes have been included in the same group (the group in this paper is called T.O.S.) assuming the same driver conditions and behavior for them.

Regarding the engine classification, 4 categories of engine size were distinguished:

- 0 cc to 125 cc
- 126 to 500 cc
- 501 to 750 cc
- Over 750 cc

As previously mentioned, characteristics of the distance travelled by different groups of riders which were also considered, came from the technical inspection stations (known by their Spanish abbreviation as ITVs) around Spain.

Methodology

From a practical point of view, this approach of collecting and merging the data in this study consisted of the following steps:

1.- Verification that the sample size was **sufficient** and analysis of the representativeness of the sample using statistics tools (e.g. testing of Pearson χ^2). Once the sample is validated, single file creation coming from the 3 source databases is carried out.

2.- **Building a comprehensive database**, based on information from the motorcycles fleet, in which there are details for the total number of motorcycles relative to one biker profile. These groups are arranged by type of bike, age of owner and engine power. An example of this can be found in Table 1:

Table 1.
Example of a bike/motorcyclist group classification

MOTORCYCLE FLEET			
Type of motorcycle	Age of the owner	Cubic capacity [cc]	number of motorcycles
SPORT	25-34	0-125	6.317
		501-750	6.683
		>750	1.850

3.- Data available from mileage and technical inspection centers in 2007 (ITVs) are added into the table, an example of which can be found in Table 2:

Table 2.
Example of a table in which previous data have been merged with data from the ITVs for a group of motorcyclists

MOTORCYCLE FLEET				ITVs	
Type of motorcycle	Age of the owner	Cubic capacity [cc]	number of motorcycles	milage per year	Nº Motorcycles ITV
SPORT	25-34	501-750	6.683	0-2.000	4
				2.001-5.000	49
				5.001-10.000	131
				10.001-15.000	59
				15.001-20.000	13
				20.001-25.000	1
				>25.000	0
		>750	1.850	0-2.000	2
				2.001-5.000	11
				5.001-10.000	20
				10.001-15.000	16
				15.001-20.000	5
				20.001-25.000	1
				>25.000	0

4.- **Accidentology data merge**, with those relating to motorcycle fleet and annual mileage travelled, distributed under the same criteria for different groups of riders. Table 3 provides an example of this:

Table 3.
Table in which all required data (motorcycle fleet, mileage, fatalities) are merged together

MOTORCYCLE FLEET				ITVs		ACCIDENTS
Type of motorcycle	Age of the owner	Cubic capacity [cc]	number of motorcycles	milage per year	Nº Motorcycles ITV	fatalities
SPORT	25-34	501-750	6.683	0-2.000	4	88
				2.001-5.000	49	
				5.001-10.000	131	
				10.001-15.000	59	
				15.001-20.000	13	
				20.001-25.000	1	
				>25.000	0	
		>750	1.850	0-2.000	2	43
				2.001-5.000	11	
				5.001-10.000	20	
				10.001-15.000	16	
				15.001-20.000	5	
				20.001-25.000	1	
				>25.000	0	

5.- Calculation of the average annual mileage for each group of motorcycle and motorcyclist. The average value of different mileage ranges which are data from ITVs is taken; e.g. if the range is 2000-5000 km/year, 3500 km/year is averaged. The ITV data is obtained considering the number of kilometers travelled by motorcycle from the last inspection to the one performed in 2007, and dividing it by the number of years passed between them. If the inspection performed in 2007 is the first ever, the mileage is going to be divided by the age of the motorcycle.

The annual mileage averages are estimated for all the motorcycles in the ITV sample, classifying them according to the driver profile. This information is then automatically associated with the annual mileage average covered by the victims belonging to the remaining motorcycle groups. This can be seen in Table 4.

Table 4.
Example of the average mileage calculation

MOTORCYCLE FLEET				ITVs		MILEAGE PER YEAR	ACCIDENTS
Type of motorcycle	Age of the owner	Cubic capacity [cc]	number of motorcycles	milage per year	Nº Motorcycles ITV	Km/year average	fatalities
SPORT	25-34	501-750	35.346	0-2.000	4	8.348	88
				2.001-5.000	49		
				5.001-10.000	131		
				10.001-15.000	59		
				15.001-20.000	13		
				20.001-25.000	1		
				>25.000	0		
		>750	11.636	0-2.000	2	9.100	43
				2.001-5.000	11		
				5.001-10.000	20		
				10.001-15.000	16		
				15.001-20.000	5		
				20.001-25.000	1		
				>25.000	0		

6.- Calculation of the accident mortality rate of each group. The number of fatalities of a specific profile is divided by the number of motorcycles corresponding in that group. An example can be seen in Table 5:

Table 5.
Example of the mortality rate ad index of risk according to exposure (IREx) calculations

MOTORCYCLE FLEET				ITVs		MILEAGE PER YEAR	ROAD ACCIDENTS		
Type of motorcycle	Age of the owner	Cubic capacity [cc]	number of motorcycles	milage per year	Nº Motorcycles ITV	Km/year average	fatalities	mortality rate	IREx fatalities [x10e-8]
SPORT	25-34	501-750	35.346	0-2.000	4	8.348	88	0,25%	29,82
				2.001-5.000	49				
				5.001-10.000	131				
				10.001-15.000	59				
				15.001-20.000	13				
				20.001-25.000	1				
				>25.000	0				
		>750	11.636	0-2.000	2	9.100	43	0,37%	40,61
				2.001-5.000	11				
				5.001-10.000	20				
				10.001-15.000	16				
				15.001-20.000	5				
				20.001-25.000	1				
				>25.000	0				

7.- The risk index according to exposure, or IREx, is the number of motorcyclist fatalities divided by the total average mileage covered by the respective group, expressed per 100m (10^8), or in other words, the accident mortality rate over the annual average mileage driven by the specific group (Equations 1 and 2).

$$IREx = \frac{\text{Total road fatalities}}{\frac{\text{mileage}}{\text{year}} \text{ of the fleet}} \times 10^8 \quad (1)$$

$$IREx = \frac{\text{Mortality rate}}{\frac{\text{mileage}}{\text{year}} \text{ of the motorcycle}} \times 10^8 \quad (2)$$

Finally, to actually assess this risk, three different indicators of victims were defined and used:

- **Absolute number of victims** (fatalities per year for each group)
- **Relative number of victims** or **accident mortality rate** (annual death toll of each group, depending on the total number of motorcycle fleet for this group)
- **Risk index based on their exposure**, or IREx (victims relative to the annual mileage travelled by the rider)

RESULTS

Once the database was created from fatal accidents, mileage and motorcycle fleet data, the analysis of the risk of having a fatal road accident in terms of exposure by mileage (IREx) was done, by taking into account the profile of the driver and/or the type of the motorcycle.

A risk index according to exposure (IREx) was defined to evaluate the degree of this risk and to precisely show the influence of the driver and motorcycle profile on the accident rates.

Absolute number of victims

This is an absolute value which does not take into account the average mileage conducted annually by each profile, or the number of motorcycles in the fleet for the same profile.

The data showed that for Spain, in 2007 **the greater numbers of fatalities in motorcycle accidents (number of deaths greater or equal to 10) were**:

- Motorcyclists of **all age groups riding a sport motorcycle**, between **501 and 750 cc**.
- Motorcyclists **over 24 years of age**, riding a **sport bike over 750 cc**.

- Motorcyclists aged **25 to 44 years old**, riding a **naked motorcycle, between 501 and 750 cc.**
- Motorcyclists **older than 24 years old**, riding **scooters of less than 126 cc**.

Mortality rate

This rate represents the relative number of deaths as a function of the number of motorcycles that comprise the fleet for that profile.

By relating this absolute number of fatalities to the total number of motorcycles of the same profile, a very accurate result can be represented for each of the profiles defined.

IDIADA's study showed that the profiles of motorcyclists with **the highest accident mortality rate (higher than 0.25%)** were:

- Young motorcyclists aged **between 18 and 24** years old, with a **sport** type of motorcycle **between 501 and 750 cc**. Accident mortality rate: 0.70%
- Young motorcyclists aged **between 18 and 24** years old, with a **sport** type of motorcycle **over 750 cc**. Accident mortality rate: 0.51%
- Young motorcyclists aged **between 25 and 34** years old, with a **sport** type of motorcycle **over 750 cc**. Accident mortality rate: 0.34%
- Young motorcyclists aged **between 18 and 24 years** old with a **large displacement cruiser motorcycle** (> **750 cc)**. Accident mortality rate: 0.76%

Index of risk according to exposure

So far in this study, the risk of a user (i.e. a motorcyclist) of having a road accident was determined by the total number of victims and their mortality rates. However, none of this data has been related in any way to the annual mileage covered by those particular profiles of motorcyclist.

The concept of accident mortality rate (percentage of deaths over the number of motorcycles for this group) will be linked directly to the annual average mileage. A driver's risk of being involved in a road accident will be assessed according to his respective distance travelled.

<u>**Accident mortality rate vs annual mileage:**</u>
With the aim of creating a first notion on the global risk indicator considering the riders' exposure, two scatter plots can be found below (the data used to plot these are: Spanish statistics of fatal accident of riders in 2007, Spanish fleet data and mileage of Spanish riders in 2007).

In Figure 4, the mortality rate of each profile is plotted against the average mileage travelled by a motorcycle belonging to this profile. On the right side, we can see three profiles whose accident mortality rate is significantly higher than the rest (red circle).

1. Young motorcyclists aged **between 18 and 24** years of age, riders of a **sport** type of motorcycle of large displacement **(>750 cc)**. This group travels on average 5,917 km/year and has an accident mortality rate of 1.71%

2. Young motorcyclists aged **between 18 and 24** years of age, riders of a **sport** type of motorcycle **between 501 and 750 cc.** This group travels on average 7,723 km/year and has an accident mortality rate of 0.80%.

3. Young motorcyclists aged **between 18 and 24** years of age, riders of a **naked** type of motorcycle of large displacement **(> 750 cc)**. This group travels on average 3,500 km/year and has an accident mortality rate of 0.56%.

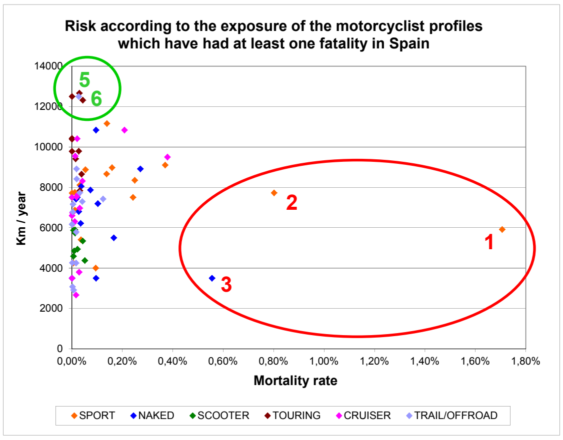

Figure 4. Risk according to the riders' exposure in Spain. All groups mentioned include data per average mileage.

The green circle encompasses the groups of riders with a **lower risk exposure,** those who are involved in accidents, but have a lower mortality rate on a relatively **high number of annual mileage**. This group of riders includes among others, the following significant groups:

1. Motorcyclists over **44 years old**, riding touring type of motorcycle of high

displacement (>750cc). This group travels on average 12,667 km/year and has an accident mortality rate of 0.03%.

2. Motorcyclists aged **between 35 and 44 years of age**, riding **touring** type of motorcycle of high displacement engine **(>750cc)**. This group travels on average 12,314 km/year and has an accident mortality rate of 0.04%.

Index of Risk according to exposure (IREx):

- IREx Definition

To assess each profile's risk exposure, an index of risk according to their exposure has been defined, where the rate of accident mortality rate comes as a function of the corresponding annual mileage travelled by that profile.

It is therefore an objective indicator of a motorcyclists' exposure to the risk of having a fatality, interpreted as the number of deaths in motorcycle accidents divided by the total average mileage covered by the respective group, expressed per 100m (10^8), or in other words, the accident mortality rate divided by the average annual mileage recorded for one motorcycle of the corresponding group, multiplied by 10^8 (see equations 1 and 2).

- IREx OF THE MOTORCYCLE ACCIDENTS IN SPAIN DURING 2007

In the bar chart below (Figure 5), the IREx for the motorcyclists killed in road accidents during 2007 is represented as defined above. This graph shows only information about profiles which have available data related with the average annual mileage. Similarly to the previous graphs, this figure was created using data relating to Spain only.

At first glance, three different but logical trends can be noticed: firstly these exposing their group's riders to high risk **[IREx > 30]**, others with relatively intermediate exposure **[10 < IREx < 30]**, and other with low exposure **[IREx < 10]**. Fortunately, as a whole, the large majority of the groups belong to the latter category of low risk exposure and in turn, there are a few groups encompassed within the higher exposure.

As seen before, the IREx value is dependent upon the number of motorcycles belonging to each profile. Having one victim in a sample of ten motorcyclists is not as representative as having 100 victims in 1000 motorcyclists, even though percentage wise they are both the same. As an example, looking at certain profiles, the small number of motorcycles that they occupy from the entire fleet causes the IREx of these groups to be particularly sensitive to the number of victims. In cases like this, the IREx value can be dependent on one or two accidents, so particular attention must be paid whilst interpreting these results. For example, motorcyclists **between 18 and 24** years of age, riding a sport type of motorcycle **between 126cc and 500cc**. There was **1 fatality** in a sample of **413 riders** in the entire Spanish motorcycle fleet. In this example, but furthermore in these cases, a minimum change of the number of victims could significantly affect the IREx value for that group. In addition these are profiles with few members which only have mileage of one motorcycle, and so the latter is extrapolated to receive the number for the entire profile-specific group, thus introducing another error that must be taken into account.

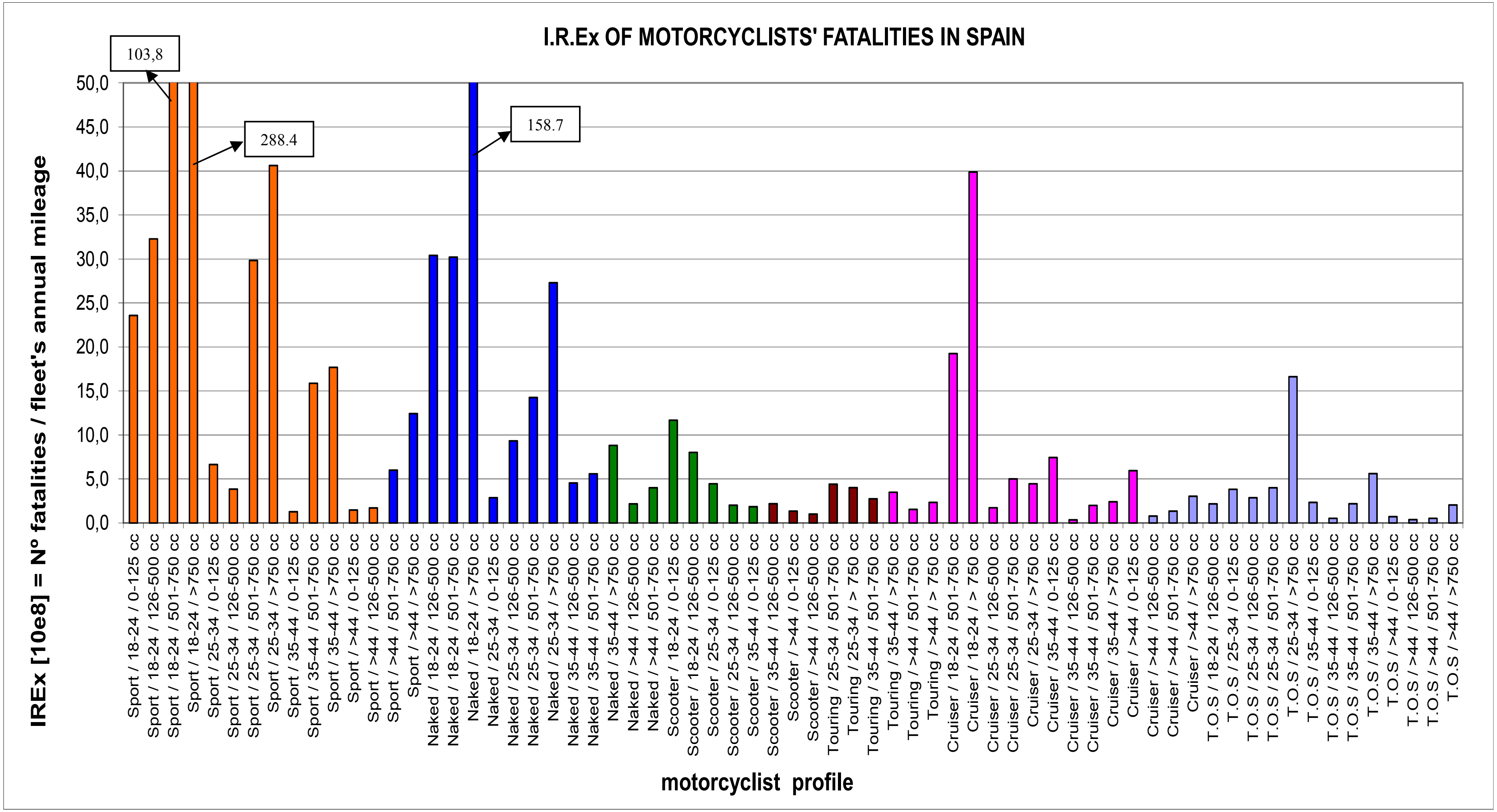

Figure 5. Index of risk according to the exposure (IREx) of the motorcyclists dead in Spain in 2007.

CONCLUSIONS

According to data published in the report of the DGT (Spanish traffic authority) “Las principales cifras de la Siniestralidad Vial: España 2008”, there were 93,161 casualty-related road accidents, resulting in 3,100 fatalities 16,488 seriously injured and 114,459 slightly injured. It is important to note that all the way through 2003 up to 2008 there has been a downward trend in fatalities per accident. **However, motorcycle related accidents have in fact seen fatality and serious injury numbers rising.**

Unlike in the past were only the total number of (motorcycle) users and their mortality rates were used to estimate the risks these users (motorcyclists) were exposed to, this study proposes the use of information related to mileage covered by each group of user (motorcyclists) in order to estimate their real risk. Moreover, this study gives these groups of motorcyclist special characteristics and focuses on distinguishing between these different profiles.

This paper presents the methodology defined and the index defined by IDIADA. The IREx (Index of Risk according to Exposure) allows us to analyze the risk of having an (fatal) accident of the different groups of riders, profiles, by taking into account the distance covered by them and their fatality statistics.

From this data file, completed with information by the motorcycle fleet, average annual mileage travelled by each group of motorcyclist and accidents, **three indicators can be defined to assess the risk exposure of these profiles**. These indicators are:

- **Absolute number of victims** (fatalities per year for each group)
- **Relative number of victims or accident mortality rate** (annual death toll of each group, depending on the total number of motorcycles for this group).
- **Risk Index according to exposure** or **IREx** (victims in relative frequency between annual mileage travelled by the motorcyclist)

Risk, in terms of the different groups' exposure, or **IREx**, is proportional to **the number of annual kilometers travelled by those groups**, i.e. a motorcyclist who covers a greater distance is exposed to a greater likelihood of having a potentially fatal road accident. However this mileage is not the only factor, as the **type of driver** and **type of motorcycle** also have a definite influence on the mortality and injury ratio of each group.

By defining this IREx indicator, which considers both accident mortality rate and annual mileage travelled, a clear and objective view of risk exposure for each group of rider (profiles) can be obtained. In the case of the Spanish study, a map of risk exposure has been laid out for each group of motorcyclists, and the appropriate measures can be taken to counter these losses.

The different groups which are analyzed in this study can be grouped according to their risk exposure. In this particular case numerical limits have been defined to allow for this classification of high, medium and low risk exposure. These limits were:

- **Groups with a high Risk Index according to Exposure indicative value.** Motorcyclists with a high accident mortality rate in relation to annual average mileage travelled belong to this group. Groups belonging in this group have an IREx value above 30 **[IREx > 30].**

- **Groups with a medium Risk Index according to Exposure indicative value.** These profiles of motorcyclist, while presenting a relatively high accident mortality rate, also do a lot of mileage. Thus, the end result is actually an average value and a balanced degree of risk exposure. The IREx value for these groups of riders stands between 10 and 30 **[10 < IREx < 30].**

- **Groups with a low Risk Index according to Exposure indicative value.** These groups of motorcyclist present a low death rate whilst covering a high number of kilometers annually. Their IREx value is below 10 **[IREx < 10]:**

The different lines in the scatter plot in Figure 6 represent the limits mentioned in the above points and divide the graph into **identified risk areas**. As in the above figures illustrated in this paper, the data represented in the following plot are only referring to Spain. In addition, in the plot below only the groups with a death rate lower than 0.35% have been considered.

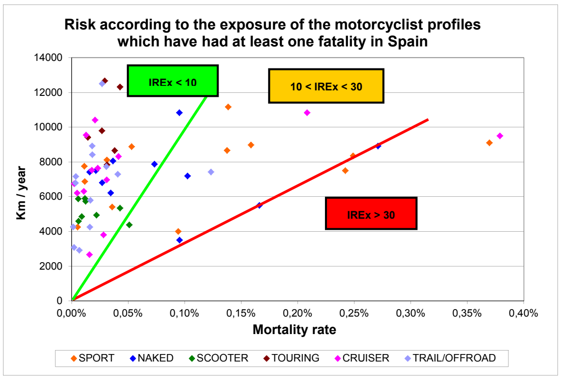

Figure 6. Identified risk areas for Spanish Motorcyclists who carry a mortality rate of less than 0.35%.

These limits can be in turn represented in a differently plotted graph, in which the motorcyclist risk groups can be more visibly distinguished (see Figure 9).

In the case of accidents in Spain in 2007, several clear trends can be identified in the results: the risk is proportional to the engine's displacement and inversely proportional to the rider's age. In other words the younger you are, and the bigger the engine of the motorcycle, the greater the chances of suffering an accident. Furthermore, it can be noted that the types of motorcycles with higher risk exposure are the sport and naked types. The following figure (Figure 7) shows this entire IREx analysis for sport type motorcycles in Spain, 2007. As can be seen, a large displacement and a young driver is a bad combination and produces the highest risk exposure.

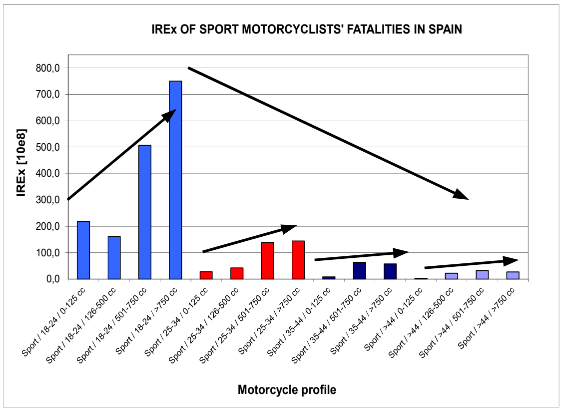

Figure 7. Risk index according to exposure for motorcyclists riding sport type of motorcycles.

Similarly to the previous figure, the graph below (Figure 8) represents the corresponding IREx values for naked motorcycles. Similar trends as the sport type can be clearly distinguished: high displacement and young driver leads to high IREx.

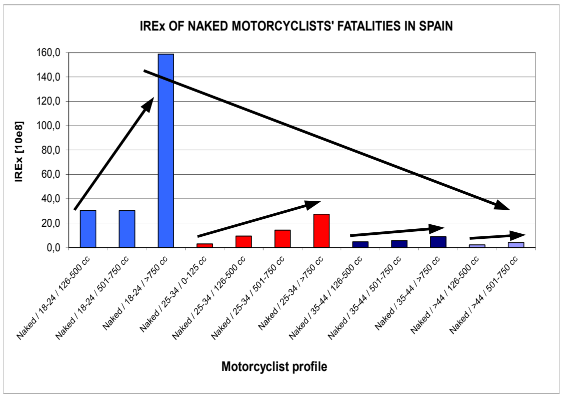

Figure 8. Risk index according to exposure for motorcyclists riding sport type of motorcycles.

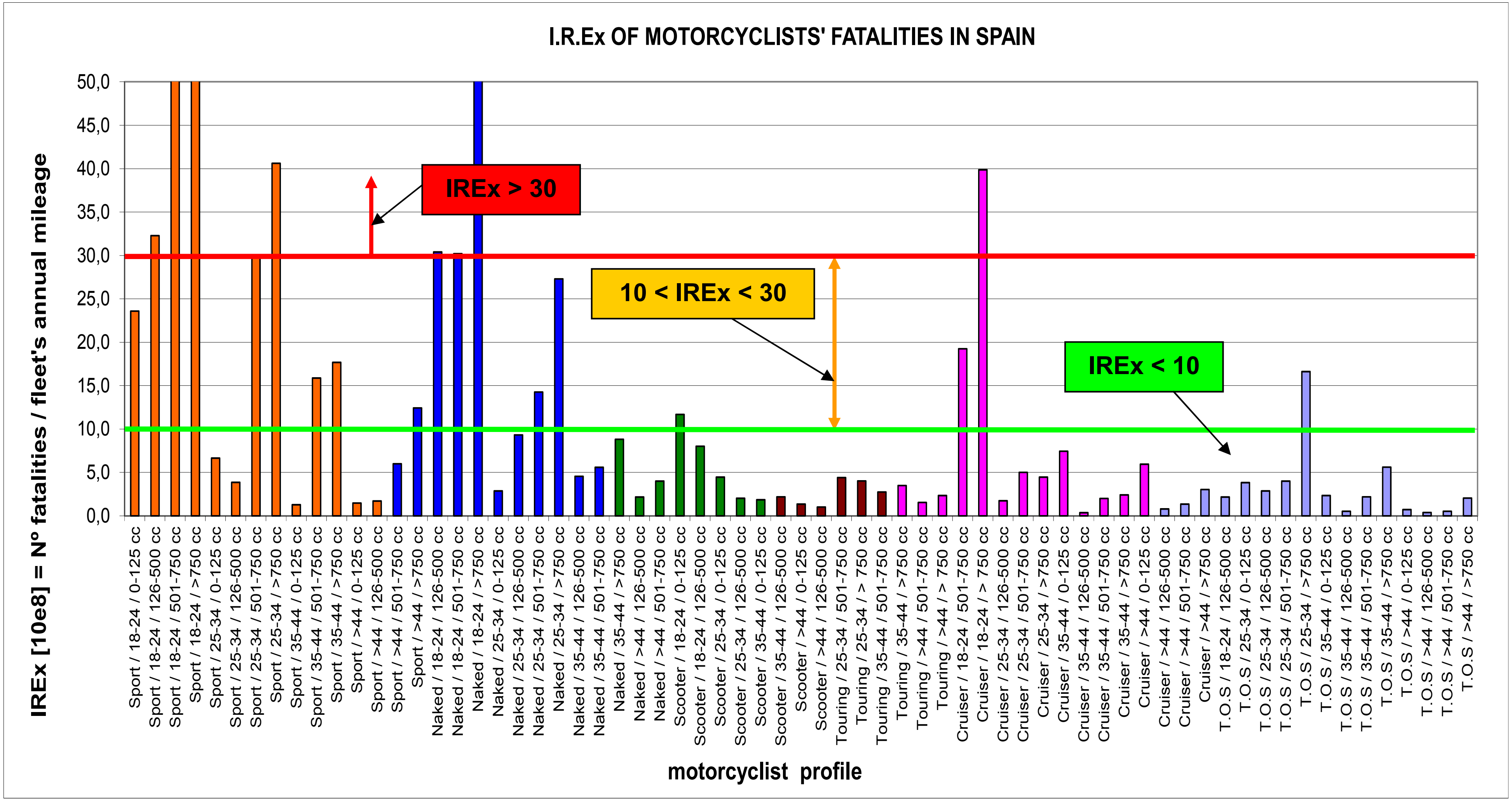

Figure 9. Risk Index according to Exposure of motorcyclists involved in road accidents in Spain, 2007.

ACKNOWLEDGEMENT

Special thanks to Mª Anuncia Ocampo from the Observatorio Nacional de Seguridad Vial (Dirección General de Tráfico) for the support in the original work. Also to Victor Salvachua from Applus ITV for the data of mileage.

ANNEX 1: CLASSIFICATION OF MOTORCYCLE TYPES

Sport:	**Naked:**
	
Scooter:	**Touring:**
	
Cruiser:	**Trail:**
	
Offroad:	**Supermotard:**
	

Figure 10. The classification of the different type of motorcycles which were involved in IDIADA's pilot study.

THE DEVELOPMENT OF A DYNAMIC ROLLOVER RATING TEST

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ABSTRACT

The goal of this research is to develop a dynamic rollover test rating system similar to the star-rating system of frontal Federal Motor Vehicle Safety Standard (FMVSS) 208 and side FMVSS 214 compliance, New Car Assessment Program (NCAP) and Insurance Institute for Highway Safety (IIHS) tests. Until now, the requirement for vehicle and occupant crashworthiness in rollovers has been a structural measure only, the vehicle's strength-to-weight ratio (SWR), in a static roof crush test.

The short-term objective of this paper is to develop a quasi-dynamic rating system based on predictions derived from the Jordan Rollover System (JRS) dynamic rollover tests, IIHS static tests and finite element parameter sensitivity studies, verified by dynamic test sampling. The rating for the protocol is based on the National Accident Sampling System (NASS) and Crash Injury Research Engineering Network (CIREN) injury risk probability functions.

One method of predicting performance is to adjust the results of a dynamically-tested vehicle, similar to the vehicle whose performance is to be predicted, by the parameter sensitivity relationships correlated to a larger number of dynamically-tested vehicles. Another method is to formulate and then apply a multivariate equation based on the correlated parameters of a larger number of dynamically-tested vehicles.

This paper presents the prediction procedure based on a limited number of vehicles with a wide range of SWRs. The intent is to apply the procedure to vehicles compliant with 2009 FMVSS 216 and, as such, the illustrations herein are examples.
In this paper, the procedure is illustrated by a calculation of two parameters, SWR and major radius (MR). Normalization procedures have also been developed to estimate real-world dynamic test protocol performance, as well as the injury measures for 5^{th}, 50^{th} and 95^{th} percentile dummies. This prediction procedure is an interim solution, not a substitute, for compliance or NCAP dynamic rollover testing.

A more detailed summary of the research basis for this effort is in a companion paper 11-0090 "Predicting and Verifying Dynamic Rollover Occupant Protection."

INTRODUCTION

The selection of parameters as possible test criteria independently or in combination was based upon results of dynamic tests by C*f*IR and other laboratories, case studies, and real-world crash databases.

The JRS test device was selected for this study. Since 2004, more than 50 dummy-occupied vehicles have been tested dynamically with the JRS. Up to 50 data channels were collected and examined as possible metrics. These included vehicle structural, dummy kinematics and injury measure data.

This study examined:

- vehicle structural measures and related injury risk, as well as
- dummy neck injury measures relative to criteria.

The degree of residual roof crush was selected as the vehicle structural measure with the corresponding probability and odds ratio of fatalities and AIS 3+ head, spinal, spinal cord injuries. These injury characteristics were based upon recent statistical analysis of NASS-CDS and CIREN data. The dummy injury measures and criteria were the Injury Assessment Reference Values (IARV) and Integrated Bending Moment (IBM) criteria.

Low-severity JRS test protocols included 1- and 2-roll dynamic tests of production and reinforced vehicles. The vehicles were compared by residual roof crush, injury risk and dummy injury measures. Disparities relative to SWR were identified and attributed to effects of other parameters that confounded the rating process. For example, dummy injury measures were also related to dynamic crush, crush speed and duration; headroom; belt excursion; and motion of the center of gravity (CG) in the ground reference plane. This study relies on the generic character of vehicles in the fleet and validating tests that can identify and factor in generic anomalies. It is not a substitute for full-scale testing, but may provide a market incentive for manufacturers to improve safety and reduce casualties.

The reliability and accuracy of the injury measures were compared to injury risk data. The structural probability of death and severe injury were correlated to the 10% probability of AIS = 3+ injury by IARV bending moments and IBM momentum exchange. In this study, the IBM was more accurate, less dependent on dummy position and more reliable than peak bending moment IARV and injury risk assessments. Dummy injury measures were related to residual roof crush. There was general correlation of dummy injury measures to one of three levels of injury risk probability.

Results of this study suggest that rollover test ratings should be a function of structural and dummy measures with vehicle-specific weightings of the most significant factors identified above. The complete formula for a rating system is:

$$\text{Rating} = f(\text{structural measures}) + f(\text{dummy injury measures}) \qquad (1).$$

The examples in this paper are focused on two parameters of the structural measures calculated from the weighted SWR and the distance between the roof rail and the roll axis or major radius (MR) as a function of residual crush. The results are roughly consistent with actual measured values.

METHODS

There were seven main contributing developments, which will be discussed in sequence:

1. a Hybrid III dummy neck modified for rollover testing,
2. rollover injury measures, criteria and injury risk,
3. a real-world dynamic rollover test protocol,
4. vehicle structural parameter sensitivity,
5. structural injury risk and dummy injury measures,
6. a protocol normalization procedure, and
7. a ratings prediction procedure

1. A Hybrid III Dummy Neck Modified for Rollover Testing

The Hybrid III dummy neck used for frontal impact testing is representative of a 27-year-old soldier with tensed musculature, and is 10 times stiffer than a normal person's untensed musculature. Neck injury risk is assessed from data measured by its upper neck load cell, whereas rollover neck injuries typically occur in the lower neck. The Hybrid III neck is axially aligned and erect, whereas a human neck has lordosis. For these reasons, the production Hybrid III neck is not a good predictor of the real-world hyperflexion injury pattern and mechanism described by Pintar et al. [1] and shown below in Figure 1.

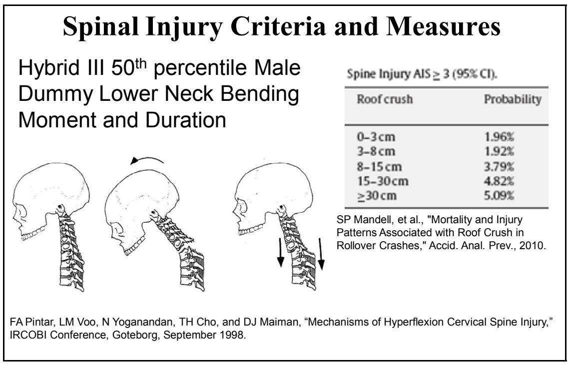

Figure 1. Spinal injury mechanism and criteria.

To compensate for these disparities, the production Hybrid III neck was modified using low-durometer butyl rubber discs with one-third the tensed soldier's musculature, a 30° inclined flexion lower neck bracket, and a lower neck load cell [2]. Tests with the modified neck reveal more realistic head-neck kinematics and injury prediction [3-5].

2. Rollover Injury Measures, Criteria and Injury Risk

Pendulum tests of the production and modified Hybrid III necks dispelled claims that short-duration peak loads are good predictors of lower neck bending injury [3-5]. Instead, a momentum exchange measure, called the Integrated Bending Moment (IBM), was developed by integrating the composite lower neck flexion moment My and the lateral moment Mx over the time duration above a minimum moment level [6]. Figure 2 illustrates the IBM as a dummy injury measure that distinguishes between production and reinforced roofs; the area under the production roof curve (more crush) is greater than the area under the reinforced roof curve (less crush).

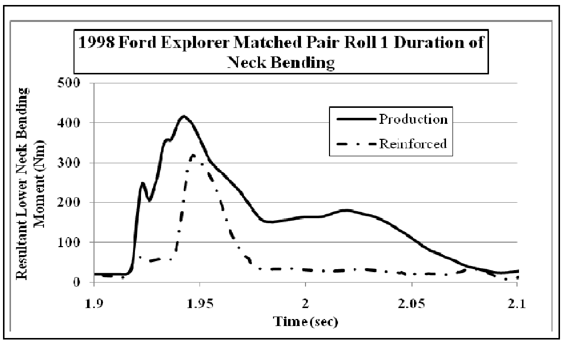

Figure 2. Illustration of IBM results.

We compared injury risk evaluations using the 2003 Mertz and Prasad IARV [7], the 1998 Pintar flexion bending moment criteria [8] and the IBM [8-9]. In more than a dozen JRS tests (see Figure 7), we found the IBM correlated well with residual crush (and injury) and was more independent of dummy head-neck position than the IARV [10].

3. A Real-World Dynamic Rollover Test Protocol

There are approximately 270,000 rollover crashes annually in the U.S., causing about 10,000 deaths and 26,000 serious injuries. A compliance test protocol is often an administrative decision about a political, technical compromise of the characteristics of the major types and severity of impacts, moderated by consideration for calculated benefits, cost and the capabilities of current production vehicles.

The objective of the 5-year multivariate NHTSA project is to define the global issue (i.e., to characterize a real-world rollover). C*f*IR seeks, more specifically, to identify the rollover segment with the greatest serious injury potential for FMVSS 216 compliant vehicles that would be consistent with a compliance or comparative evaluation dynamic rollover test. This process requires evaluating the injury potential sensitivity of each segment and its influence on the following segment. Since it has been shown that 95% of single vehicle rollovers and serious-to-fatal injuries occur within 8 quarter turns [11], we defined 10 segments of a 2-roll event and analyzed their consequences in Table 1 below. Segment 5, where the "vehicle roof impacts with the road" with the "potential for severe head/neck/ spine injuries," is the obvious choice for a test protocol.

Table 1.
Segments of the roll sequence and their potential for injury

Segments of the Roll Sequence	Potential for Serious to Fatal Injury
1. Vehicle loss of control	Non-injurious
2. Yaw-to-trip orientation	Occupants move laterally out-of-position
3. Trip	Exacerbates lateral out-of-position
4. Roll rate	Potential for far side injury and ejection
5. Vehicle roof impacts with the road	Potential for severe head/neck/spine injury.
6. Wheel/underbody contacts	Potential for lower spine injuries
7. Suspension rebound and second roll lofting	Non-injurious
8. Near-side roof impact, roll slowing ejection	Potentially injurious
9. Far-side impact	Potentially injurious
10. Wheel contact to rest	Non-injurious

We performed a logical technical analysis of Malibu dolly rollover tests [12], over 400 rollover crash investigations [13], rollover crash statistics, the capabilities of the JRS rollover crash test machine [14], two-sided National Highway Safety Bureau's (NHSB) and M216 data, Hybrid III dummy and IARV, JRS rollover database and biomechanical epidemiology data and derived the proposed protocol described below in Table 2.

Table 2.
Proposed real-world rollover protocol

The Proposed Real-World Rollover Protocol

- Road speed 20 mph ± 5 mph
- Roll rate @ near-side impact 270 °/sec ± 20%
- Pitch 10° ± 5°
- Roll angle at impact 135° ± 10° and/or 185°
- Drop height 10 cm to 22 cm (4 to 9 inches)
- Yaw angle 15° ± 15°
- Dummy initially tethered @ 1 g and 60° toward the near side.

4. Vehicle Structural Parameter Sensitivity

Residual and cumulative vehicle roof crush has been found to be sensitive to several vehicle parameters (e.g., SWR, pitch, roof elasticity and road speed/roll rate).

Strength to weight ratio In 2008, JRS roof crush data plotted as a function of SWR had about the same slope as IIHS' analysis to an SWR of 4 and injury risk to about 4 or 5% [15]. That chart incorrectly projected the JRS data to an SWR of 5. Subsequent tests of vehicles with SWR above 4 show a substantially reduced effectiveness with increasing SWR. The example in this paper considers the performance of vehicles with SWRs from 2.1 to 6.8. This wide range is not representative of future vehicles, but results in the revised SWR versus cumulative residual crush in Figure 3 and demonstrates the effectiveness of the procedure. The highlighted point is a real test result of the limited number of vehicles plotted.

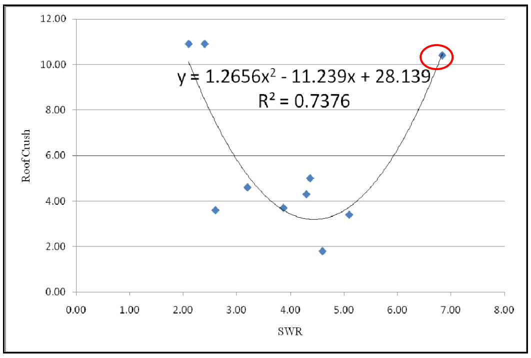

Figure 3. Residual roof crush vs. SWR.

Vehicle pitch A case-by-case study of 273 serious injury rollover crashes contained in NASS shows that more than 80% of the study vehicles had hood and top of fender damage that could only have occurred as a result of a roll with more than 10° pitch. The JRS test results in Figure 4 show the effect of pitch; there was greater residual crush at 10° of pitch compared to similar tests at 5° of pitch after roll 2.

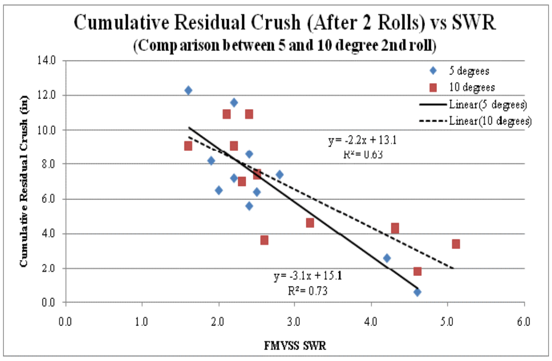

Figure 4. Comparison of residual crush vs. SWR after roll 2 at 5° vs. 10° pitch.

The diverging correlation lines show that, for vehicles with an SWR less than 3, there is little or no difference between the cumulative residual crush in second rolls at 5° and at 10° pitch. However, there is a large difference (60-175%) between the cumulative residual crush at 5° and 10° pitch for vehicles with SWRs greater than 3.

Major radius A vehicle's MR is the distance between the CG longitudinal (roll) axis and the roof rail at the A-pillar. The scatter plot of Figure 5 identifies the vehicles involved, their real-world and the cumulative residual crush at the A-pillar in a 2-roll event. The relationship is particularly striking for the slope, which indicates that each 1.2-inch change in MR affects the cumulative residual crush by 1 inch.

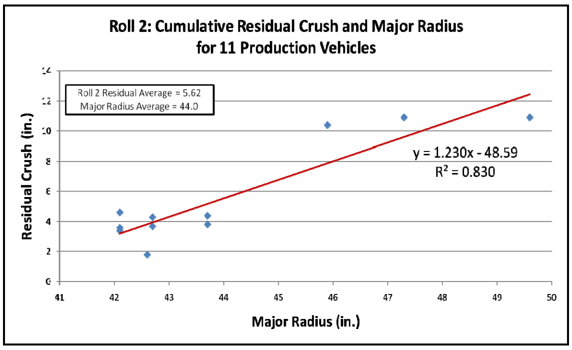

Figure 5. Cumulative Residual Crush vs. MR.

5. Structural Injury Risk vs. Dummy Injury Measures

Injury risk vs. residual roof crush Figure 6 is a plot of injury risk as a function of residual crush as defined by Mandell, et al. [16]. It shows from NASS and CIREN data that the probability of death and serious-to-fatal head, spine and spinal cord injury increases rapidly with cumulative residual crush over the occupant's seating position.

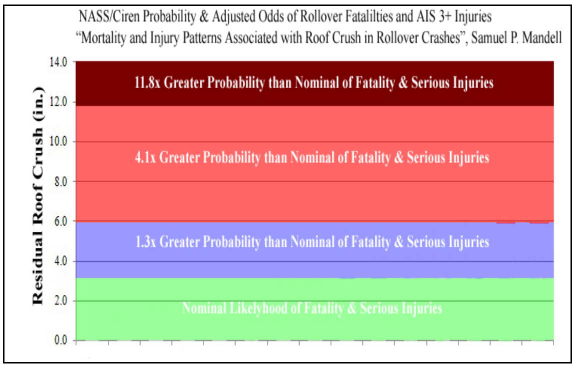

Figure 6. NASS/CIREN probability and adjusted odds.

Dummy injury measure vs. residual roof crush Figure 7 is a scatter plot of residual crush and the IBM for a 15 mph, 190°/sec, 5° pitch roll. The plot shows unacceptable neck injury severity for an IBM of 13.5 or more.

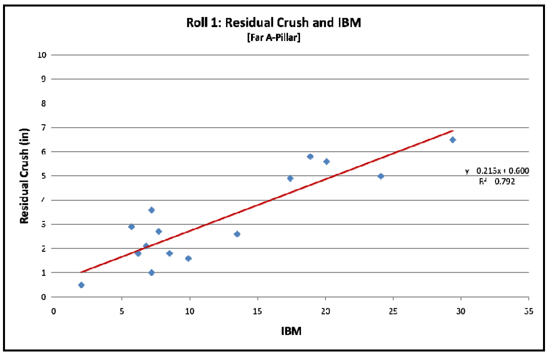

Figure 7. Residual crush vs. IBM.

Residual headroom vs. IBM The scatter plot of Figure 8 shows the effect of post-crash residual headroom and indicates that an IBM of 13.5 corresponds to1 inch of post-crash positive headroom. NHTSA has reported that post-crash negative headroom is 5 times more injurious than no or positive headroom.

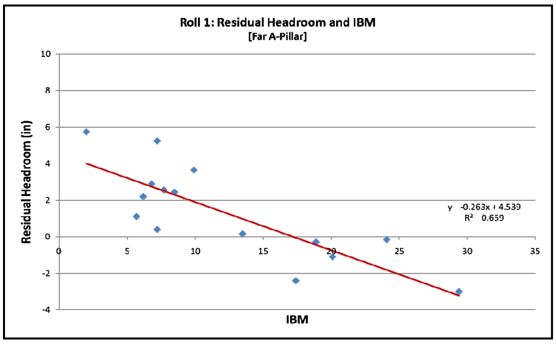

Figure 8. Residual headroom vs. IBM.

Roadbed speed and proportional roll rate Figure 9 shows that, when the residual crush is averaged for each roadbed speed with its proportional roll rate, the correlation is good. We found about 40% more residual crush at 21 mph than at 15 mph.

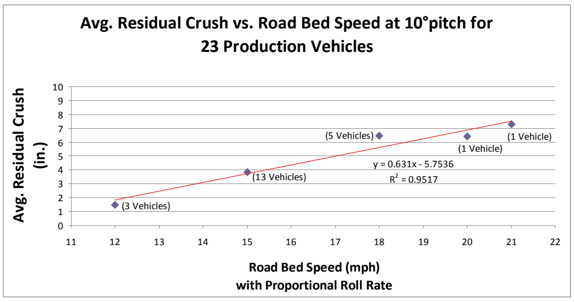

Figure 9. Residual crush vs. road bed speed.

Headroom and anthropometry The headroom for the 50th percentile Hybrid III dummy was measured preceding each test. In many cases, the motion off the seat was also measured during the test. The seated height of the 50ttj and 95th percentile males are 35.5 and 38.5 inches, respectively, while that of the 5th percentile female is approximately 32 inches. An estimated adjustment for headroom for the 5th and 95th relative to the tested 50th percentile male is plus and minus 3 inches, respectively.

Lap-and-shoulder belt A series of spit tests with 5th, 50th and 95th percentile volunteers at roll rates to 200 °/sec, the belted occupant's upward motion off the seat varied from 3 to 5 inches in a sequence of 3 to 5 rolls. When a representative seat belt pretensioner was fired, the occupant's motion was reduced by about 2 inches.

6. A Protocol Normalization Procedure

This procedure was developed to put all the data of the 50 JRS tests on a level rating system. It is also useful to relate the data to any protocol that National Highway Transportation Safety Administration (NHTSA) or University of Virginia (UVa) or George Washington University (GWU) derive as the "Real-World Rollover Test Protocol."

In order to compare the 1-roll performance of vehicles, we normalized the residual crush at the A-pillar (after 1 roll) for all vehicles to a 1-roll event at 10° pitch and 21 mph. This was done by increasing or decreasing the amount of residual crush by the ratio of the different test speeds in addition to increasing the amount of residual crush for a 5° pitch roll by 20% as determined empirically. For example, a vehicle tested at 5° pitch and 15 mph would have its residual crush increased by 60%; 40% (21/15 = 1.4) because of the difference in road speed and proportional roll rate and 20% for the pitch increase from 5° to 10°. In order to compare the 2-roll performance of vehicles tested at different protocols, we normalized the cumulative residual crush (after 2 rolls) for all vehicles to a roll sequence of 5°/15 mph roll 1 and 10°/15 mph roll 2. This was done by comparing the difference in cumulative residual crush between the 5° and 10° pitch roll 2 (at 15 mph), where roll 1 was conducted at 5° pitch and 15 mph as shown in Figure 4.

It should be noted that almost all JRS roof crush measurements were taken from string potentiometers from the roof rail to the roll axis and unless resolved by the tracking cameras should be considered as radial measurements at about 35 to 40º. Since the NASS/CIREN injury risk probability functions are based on vertical crush, for general comparison purposes, a rule of thumb is to reduce the radial value by 20%. The result is shown in Figure 10.

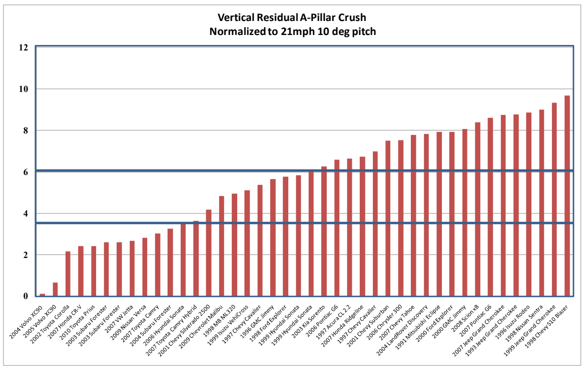

Figure 10. Vertical residual A-pillar crush.

Figure 10 confirms the Austin [17] and Strashny [18] statistical injury analysis and identifies the probability of injury to various body parts by Mandell [16] as a function of residual roof crush. This chart is normalized (from 5° pitch protocols for 10° pitch test data not previously considered in [19] to a 21 mph, 10°, 270 °/sec roll rate, 145° impact angle and 4-inch drop height. It is also corrected to vertical from radial JRS crush measurements.

The primary difference between these dynamic tests and FMVSS 216 static tests is the ability to grade vehicle compliance by injury risk and dummy injury measure (IBM) performance and to identify the effect of occupant protection features, as well as anomalies between the two. The horizontal lines delineate the injury probability levels of the Mandell chart of Figure 6.

The area below the first line at 3.5 inches represents "GOOD" performance. The area below the second line at 6 inches represents a 30%

increased probability of death and serious injury and would be “ACCEPTABLE”. The area above the 6-inch line and below 12 inches represents 4.1 times the probability of death and injury and would be rated “POOR”. Only vehicles of the 1980’s and early 1990’s should rate in the area above 12 inches, where the probability of death and injury is 11.8 times the nominally good performance.

Within this set of 40 JRS tests are 15 vehicles involved in 188 real-world rollover crashes investigated by the authors with catastrophic AIS 4 to 6 injuries which were the subject of extensively detailed investigation. Those 188 victims in every case validated this injury risk analysis. These normalized to the real-world protocol dynamic test results demonstrate the ability to comparatively rate vehicles by residual crush and injury risk.

7. A Ratings Prediction Procedure

<u>Prediction of structural injury risk and dummy injury measure performance of new vehicles</u> The analysis of parameter sensitivity to intrusion identified three significantly correlated factors: SWR, MR and Elasticity (recoverable deformation).

One method of predicting performance is to adjust the results of a dynamically-tested vehicle, similar to the vehicle whose performance is to be predicted, by the parameter sensitivity relationships that have been correlated to a representative sampling of dynamically-tested vehicles.

For a simple example, the cumulative intrusion of a 2004 Chevrolet Malibu with an SWR of 2.18 can be predicted from the already-tested 2009 Chevrolet Malibu with an SWR of 4.4. The body parameters, height, width, CG location and real-world are virtually the same as shown in Table 3. From Figure 3, the variation in SWR between 2.18 and 4.4 corresponds to a ratio of roof crush of 8.5/3.5 or 2.4. Since the crush in the 2009 vehicle was 5 inches, the crush in the 2004 vehicle under the same conditions would be 2.4 x 5 = 12 inches.

Table 3.
Predicting the 2004 Malibu cumulative crush from a 2009 Chevrolet Malibu

Vehicle	SWR	Cumulative Crush (in) Roll 2	Weight (lbs)	Height/ Width (in)	CG (in)	MR (in)
2004 Chevrolet Malibu	2.16	12	3262	58/70	22.8	40.1
2009 Chevrolet Malibu	4.37	5	3642	57/70	22.4	40.1

The second more accurate and sophisticated method is to formulate and use a multivariate analysis of all the parameter variations to optimize the prediction of new vehicles as tested to the real-world dynamic test protocol performance.

A multivariate analysis has not yet been conducted. However, Table 4 is a crude illustration, using two simple functions (instead of the multivariate functions) to weight the SWR relationship of Figure 3 and the MR of Figure 5.

In the illustration of Table 4, we calculated the residual crush for each vehicle for its SWR, from Figure 3. We also calculated the residual crush for its MR, from Figure 5. We then assumed that the crush contribution of SWR and MR represented the only factors contributing to the total and weighted them accordingly. We optimized the result by adjusting the weightings in 5% increments; a 55% SWR and 45% MR yielded the best fit.

Table 4.
Predicted crush vs. measured crush

Vehicle	Strength to Weight Ratio	Major Radius	Calculated Cumulative Radial Crush *f*(SWR) + *f*(MR)	Measured Radial Roof Crush
2007 Chevy Tahoe	2.10	49.6	10.82	10.90
2007 Honda Ridgeline	2.40	47.3	8.81	10.90
2007 Honda CR-V	2.60	42.1	5.82	3.60
2006 Hyundai Sonata	3.20	42.1	4.54	4.60
2007 Toyota Camry Hybrid	3.87	42.7	3.97	3.70
2007 Toyota Camry	4.30	42.7	3.76	4.30
2009 Malibu	4.37	40.1	2.53	5.00
2005 Volvo XC90	4.60	42.6	3.72	1.80
2007 VW Jetta	5.10	42.1	3.77	3.40
2008 Scion xB	6.84	45.9	9.27	10.40

Figure 11 compares the calculated/predicted results to actual measured intrusion. It shows that, in spite of the simple two-factor analysis and the broad range of SWRs, there is a reasonable semblance of comparable injury risk.

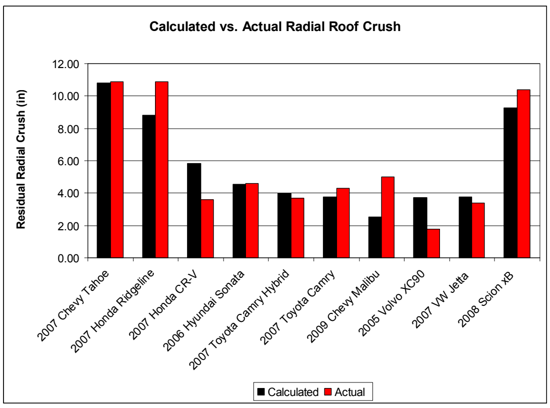

Figure 11. Calculated vs. actual roof crush.

The <u>structural rating</u> is the ratio of injury risk versus vertical residual crush in the NASS/CIREN statistical probability of fatality and head, spine and spinal cord serious injury data chart and consists of the SWR, MR and Elasticity terms in the following equation:

$$\text{Severity (S) x } \{f(\text{SWR}) + f(\text{MR}) + f(\text{Elasticity})\} = \text{Structural/Injury Risk Rating} \quad (2).$$

While the equation for the dummy injury measure rating for the probability of AIS ≥ 3 lower neck flexion bending injury is:

$$\text{Severity (S) x } \{f(\text{SWR}) + f(\text{MR}) + f(\text{Elasticity}) + f(\text{Headroom}) + f(\text{Belt Pretensioning}\} \text{ x } f(\text{IBM}) = \text{Dummy Injury Measure Rating} \quad (3).$$

where:

Severity (S) is the percent increase in traveling speed and proportional roll rate protocol over the nominal 2-roll, 15 mph, 190 °/sec, 4-inch drop height, and 5° and then 10° pitch test.

To predict injury measures from the 50th for the 95th percentile male reduce HR by 3 inches and for a 5th percentile female increase HR by 3 inches. For persons 30% or more overweight in their size category reduce HR by 3 inches.

CONCLUSIONS

1. A real-world research protocol has been characterized and the segments have been analyzed for injury potential. For the compliance test, we identified the first roll ballistic segment as most likely to produce serious-to-fatal injury.
2. Dynamic JRS rollover tests of 40 vehicles with various protocols have been normalized to represent the first roll of a real-world protocol and matched to NASS/CIREN injury risk potential to various body parts.
3. Dynamic JRS tests provide detailed dummy injury measure potential assessments, not possible with static tests. JRS injury potential assessments are:
   - the rollover equivalent of frontal and side dynamic test injury potential,
   - comparative, instructive and relevant to a final real-world protocol,
   - determinate of individual vehicle injury risk and dummy injury measure ratings,
   - relative to statistically-derived criteria for injury risk and dummy injury measures,
   - inclusive of the dummy injury measure effects of occupant protection features,
   - likely to eliminate more casualties sooner than the regulatory comprehensive plan,
   - insightful for and supplemental to rollover injury research, and
   - useful in conjunction with consumer information as incentives to manufacturers.
4. NHTSA's 5-year research plan complements and will eventually validate this cooperative project to develop a real-world comparative evaluation and compliance test rating system.

ACKNOWLEDGEMENT

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EVALUATION OF THE CAR SAFETY ENHANCEMENTS DURING THE LAST THREE DECADES

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ABSTRACT

The objective of this work is to assess the enhancement of new cars (designed in the 2000's) compared to cars designed in the 1980's and in the 1990's. The improvement is evaluated according to two criteria: the involvement rate in an accident and the protection offered to the driver in case of a crash. Within each decade of conception, cars are also defined and evaluated regarding their classes (supermini, small family car, large family car, Mpv and executive).

Protection is analyzed through the risk of fatal and severe injuries among drivers involved in a crash. Regarding involvement, as no data on the circulating fleet and on the characteristics of the circulating drivers are available, the involvement rate is estimated by the risk of being responsible for an accident. Logistic regressions were fitted for the two indicators, in order to avoid confounding factors.

Data sources consist on the French accident national data base from year 2007 to 2009. This data base gathers all injury accidents occurred each year in France. Information regarding the circumstances of the accident, the vehicles, the people involved and their injury severity are available. Cars designed in the 1980's, the 1990's and in the 2000's were selected, and the class of the cars is assigned for each vehicle. The study is based on a final sample of 97 600 car drivers.

Results are given in term of safety benefits with their 95% confidence intervals. The increase or decrease in the risk of being responsible for an injury accident is presented for each category of cars, as well as the risk of being killed or severely injured. Cars are then compared according to their decades of conception and to their classes.

The study enlightens the safety improvements made since the 1980's, in term of risk of being involved in an injury accident but also in term of protection offered by car. The magnitude of the improvement turns up to be dependant on the category of the car.

The sample used is mostly European but the methodology could be applied on different countries accident databases.

This study provides an evaluation of car protection on recent accident and also brings new data on involvement risk according both to the conception and class of the cars.

INTRODUCTION

In France, the number of people killed in a road accident is in constant decline since 2002. The figures of year 2009 allow recording a total reduction of 20 % during the last 5 years.

The figures of the road accidents in France are supplied by the National Inter-Departmental Observatory on Road Safety (Observatoire National Interministériel de Sécurité Routière: ONISR), which collects the reports on injury traffic accidents (Bulletins d'Analyse d'Accident Corporel de la circulation: BAAC) compiled by the Police and Gendarmerie. In 2009, 4273 persons died in a road accident (immediately or at 30 days), against 5318 in 2005. If the mortality rate of the road accidents goes down, the improvement does not concern all the users in the same way. The decline observed concerns essentially drivers and passengers of passenger cars.

The objective of this work is to assess the enhancement of the most recent vehicles compared to vehicles of the other generations. The improvement is evaluated according to two criteria: the protection offered to the driver in case of a crash and the involvement rate in an accident.

DATA

The study is carried out on the French accident national data base (BAAC) of year 2007 to 2009. Police officers fill up a form for each injury road accident happening in France, these forms contribute to populate the database. The information provided by the database deals with the general characteristics of the accident (such as luminosity, rural/urban area, junction related accident…), the type of infrastructure where the accident took place. The vehicles involved are described (type, year of first registration), also with their type of impact and obstacle. Regarding the occupants, their age, gender, status of wearing or not the seat belt are documented. The injury severity is coded for each occupant involved in an injury accident. Since January 2005, the injury severity is assigned as follows:

- Fatally injured: occupant killed within 30 days after the accident.
- Severely injured: injured occupant who stayed at hospital more than 24 hours.
- Slightly injured: injured occupant who stayed at hospital less than 24 hours.
- Not injured

The makes and models of the vehicles are established from the Vehicle Identification Number (VIN) filled in the database by the Police forces. The accident data are linked with a fleet data which also provides the year of conception of the models. The year of conception stands for the first year the model appears on the French market. There may be some missing or incorrect value for the VIN. As a result, 70% of the involved vehicle has been identified in the database. The analysis is performed on the vehicle for which the makes, model and year of conception are known. Accidents against pedestrians or two wheelers are not taking into account in the study, as passenger car occupants involved against vulnerable road users are commonly uninjured whatever the year of conception of the car. Those types of crashes don't allow grasping the enhancement of protection through the years.

At the end, our sample consists of 97 747 drivers with makes, models and year of registration of the passenger car known. Vehicles are then classified by class and year of conception. Classes of vehicles are available on EuroNCAP website: Supermini (Sm), small family car (Sfc), large family car (Lfc), and executive cars (Exe). Small and large MPV are grouped together as MPV (Mpv). Picks up, small and large off-road 4x4 are kept in the sample but no results will be provided as their number is small. Year of conception were set up in three groups: 1980-1989, 1990-1999, 2000-2009. On the whole, 18 classes of vehicles could be defined as presented in table 1.

Table 1.

Table 1.
Distribution of the classes and phase of conception of the crashed passenger cars in France (BAAC 2007 - 2009)

Class – phase of conception	n
Supermini car 1980-1989	7 045
Supermini car 1990-1999	27 861
Supermini car 2000-2009	8 171
Small family car 1980-1989	3 317
Small family car 1990-1999	14 057
Small family car 2000-2009	6 678
Large family car 1980-1989	2 940
Large family car 1990-1999	6 519
Large family car 2000-2009	2 860
Executive car 1980-1989	1 250
Executive car 1990-1999	2 496
Executive car 2000-2009	1328
Mpv 1980-1989	161
Mpv 1990-1999	6 366
Mpv 2000-2009	4 092
Pick-up 4x4 1980-1989	502
Pick-up 4x4 1990-1999	836
Pick-up 4x4 2000-2009	1268
Total	97747

The figure 1 below illustrates the frequency of the different year of conception of the crashed cars, in accidents occurred between 2007 and 2009.

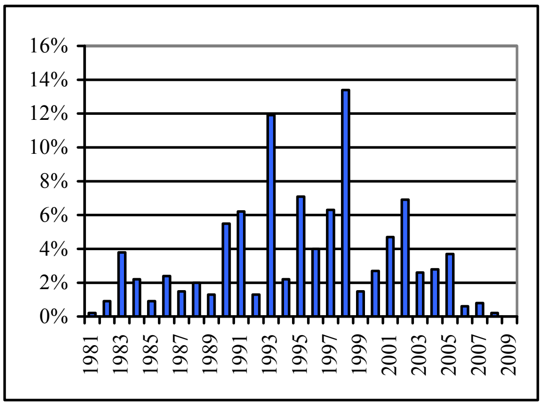

Figure 1. Distribution of the year of conception of the crashed cars, accidents without vulnerable road users, years 2007 to 2009 France.

These most recently designed vehicles (year conception 2007-2009) only represent 1% of the sample. Therefore a focus on these vehicles would have lead to very few statistically significant results.

METHODOLOGY

Protection

The evaluation of the improvement of the protection for drivers of cars designed in the 2000' compared to the 1990' and 1980', is made through the use of Odd ratio (OR). Proportion of fatally and severely injured drivers in vehicles X of a given make, model and phase of conception is compared to the proportion observed in vehicles R of another make, model and phase of conception chosen as a reference (Equation 1).

$$OR = [(Fatal+severe)/(slight+uninjured)]_{in\ veh.\ X} / [(Fatal+severe)/(slight+uninjured)]_{in\ veh.\ R} \quad (1).$$

The safety benefit observed is calculated as in Equation 2 [1]:

$$\text{Safety Benefit} = 1 - OR \quad (2).$$

This is a measure of the decrease (or increase) in the risk of being killed or severely injured for drivers of vehicle X compared to driver of vehicle. Confidence intervals at 95% are calculated as stated in [2].

Involvement in accident

In order to quantify and compare the accident involvement of each category of cars, a measure of exposure, as the mileage driven by each class of vehicle or the circulating fleet by type of cars, is needed. These figures would be the best estimator of the exposure to the risk of accident. As they are not available, the quasi induced exposure method is applied. The assumption of this methodology is that the non-responsible drivers involved in accident are likely to behave as the non involved drivers and thus they could give good approximation of the characteristic of the traveling vehicles [3]. In the database used for the analysis, responsibility for the crash is assigned to each vehicle by the police forces (responsible or non-responsible). The non responsible drivers will be the reference group, with precise characteristics known from the database (age and gender of the driver, circumstance of travel), in place of the French vehicle fleet. Responsible drivers are compared to the non-responsible ones, and accident involvement is approximated by the risk of being responsible of an injury accident. A comparison is made between the number of responsible drivers and the number of non responsible drivers of a given vehicle X, relative to the figure observed for a reference vehicle R. This can be made through the use of Odd ratio (equation 3).

$$OR = (Responsible)/(Non\text{-}responsible)_{in\ veh.\ X} / (Responsible)/(Non\text{-}responsible)_{in\ veh.\ R} \quad (3).$$

Adjusted Odd Ratio

Logistic regression is performed to take into account possible confounders in the estimation of the OR linked with the protection and involvement. Safety benefits, as expressed in equation 2, are then calculated with the adjusted OR. Table 2 details the confounding factors taken in the regression models for the protection and involvement evaluation.

Table 2.
Variable used as possible confounding factor for involvement and protection evaluation.

Variables	Involvement	Protection
type of impact (front, lateral, back, roll over, unknown)		x
Gender of the driver (female/male)	x	x
Age of the driver (<26, 26-45, 46-55, 56-65, 66+)	x	x
Seat belt worn (yes/others)		x
Accident at a junction (yes/no)		x
Luminosity (day/dark)	x	x
Slippery pavement (yes/no)	x	x
Scene (urban area, highway, national road in rural area, secondary road in rural area)	x	x
Blood Alcohol Concentration BAC (under the limit, over the limit, unknown)	x	x

RESULTS

Protection

This paragraph presents the comparison of the proportions of fatally and severely injured users according to the passenger car generations and classes. Logistic regression requires selecting a modality in each variable that serves as a reference for comparison. Being the most numerous, the vehicles of the Supermini class designed in the 1990s will serve as reference.

Variables with a significant impact on the risk of being severely, injured or killed according to the generation and the category are as follows: blood alcohol concentration, type of impact, scene of the accident, age of the driver, seat belt worn, the luminosity, gender of the driver and some interactions.
The table 3 indicates adjusted Odd ratios associated with each vehicle of the supermini class 1990's, as well as the 95% confidence intervals.

Table 3.
Odd ratios associated with the risk of being severely injured or killed for the drivers of light vehicles. Crash without pedestrian or two wheelers. 2007-2009 BAAC.

comparison	odd ratio	confidence intervals (95%)	
Sm 80s vs Sm 90s	1,511	1,418	1,609
Sm 90s vs Sm 90s	1		
Sm 00s vs Sm 90s	0,762	0,714	0,814
Sfc 80s vs Sm 90s	1,215	1,114	1,325
Sfc 90s vs Sm 90s	0,93	0,883	0,979
Sfc 00s vs Sm 90s	0,629	0,584	0,677
Lfc 80s vs Sm 90s	1,11	1,011	1,22
Lfc 90s vs Sm 90s	0,817	0,761	0,876
Lfc 00s vs Sm 90s	0,515	0,46	0,577
Exe 80s vs Sm 90s	0,961	0,834	1,109
Exe 90s vs Sm 90s	0,675	0,605	0,754
Exe 00s vs Sm 90s	0,502	0,424	0,595
Mpv 80s vs Sm 90s	0,782	0,523	1,169
Mpv 90s vs Sm 90s	0,724	0,673	0,78
Mpv 00s vs Sm 90s	0,57	0,518	0,628

The figure 2 indicates Odd ratio values associated with each vehicle of the supermini class 1990's, as well as the 95% confidence intervals.

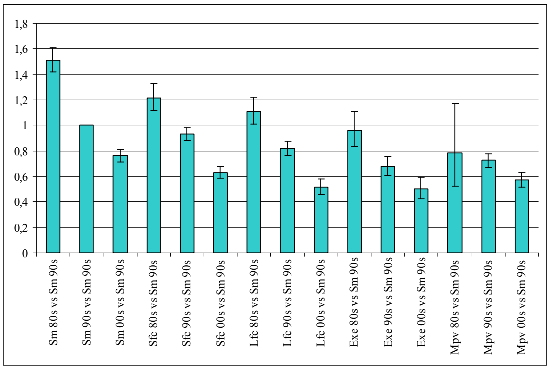

Figure 2. Odd ratios associated with the risk of being severely injured or killed for the drivers of passenger cars. Crash without pedestrian or two wheelers. 2007-2009 BAAC.

The table 4 presents the safety benefits (calculated as in equation 2) in protection according to the generations of conception for each vehicle classes. For example, the first line of table 4 compares the level of protection in supermini 90's to supermini 80's: the risk of being fatally or severely injured is reduced by 34% [29% ; 38%] for drivers of supermini 90's. None significant results are shown by a star (*).

Table 4.
Benefits in protection. Comparison between two decades for the same class.

	1990s vs 1980s		
	Benefits	CI low	CI high
Supermini	34%	29%	38%
Small familly car	23%	16%	30%
Large familly car	26%	18%	34%
Executive	30%	16%	41%
Mpv	7%*	-39%	38%
	2000s vs 1990s		
Supermini	24%	19%	29%
Small familly car	32%	27%	38%
Large familly car	37%	29%	44%
Executive	26%	10%	39%
Mpv	21%	12%	30%
	2000s vs 1980s		
Supermini	50%	45%	53%
Small familly car	48%	42%	53%
Large familly car	54%	47%	60%
Executive	48%	35%	58%
Mpv	27%*	-10%	52%

One can see the severity decreased by 23 to 30% when we compare the 90's passenger cars to 80's passenger cars. The decrease is identical when we compare 2000's passenger cars to 90's passenger cars (21 to 37% according to the vehicle classes). The overall decrease is evaluated between 48 and 54% according to the vehicle class when we compare 2000's to 80's passenger cars.

If we compare the level of protection between the classes, the same downward trend is observed whatever the decades of conception: class supermini (less protective), small family car, large family car and executive (more protective). Nevertheless, all the related differences between classes in different decade are not statistical significant. Note the protection differences between supermini class and executive class are constant through the decades (36-33-34% respectively).

Involvement in accident

For evaluation of accidental involvement via the risk of being responsible for an injury accident, the references for the logistic regression will be the supermini 90's.

Variables kept in the logistic regression to explain the risk of being responsible for a traffic accident according to the class and to the generation of the vehicle are the following ones: blood alcohol concentration, age of the driver, scene of the

accident, driver gender and slippery pavement and some interactions.
The table 5 details adjusted odd ratios associated to every type of vehicles, for the accidental involvement.

Table 5.
Odd ratio associated with the risk of being responsible for a traffic accident for the drivers of passenger cars. Accidents without pedestrian or two wheelers. 2007-2009 BAAC.

comparison	odd ratio	confidence intervals (95%)	
Sm 80s vs Sm 90s	1,096	1,037	1,159
Sm 90s vs Sm 90s	1		
Sm 00s vs Sm 90s	0,885	0,84	0,932
Sfc 80s vs Sm 90s	1,163	1,077	1,257
Sfc 90s vs Sm 90s	1,06	1,015	1,107
Sfc 00s vs Sm 90s	0,804	0,759	0,852
Lfc 80s vs Sm 90s	1,129	1,04	1,225
Lfc 90s vs Sm 90s	0,983	0,928	1,042
Lfc 00s vs Sm 90s	0,764	0,703	0,83
Exe 80s vs Sm 90s	1,237	1,094	1,398
Exe 90s vs Sm 90s	1,159	1,061	1,266
Exe 00s vs Sm 90s	0,783	0,696	0,882
Mpv 80s vs Sm 90s	1,135	0,811	1,589
Mpv 90s vs Sm 90s	0,816	0,769	0,865
Mpv 00s vs Sm 90s	0,744	0,693	0,799

The figure 3 indicates Odd ratios values associated with each vehicle of the supermini class 1990s, as well as the 95% confidence intervals.

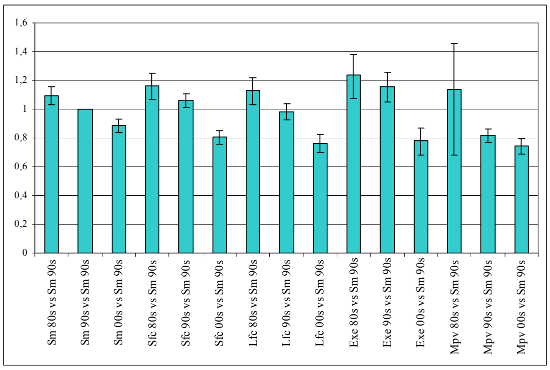

Figure 3. Odd ratio associated with the risk of being responsible for a traffic accident for the drivers of passenger cars. Accidents without pedestrian or two wheelers. 2007-2009 BAAC.

The table 6 presents the safety benefits (calculated as in equation 2) in involvement according to the generations of conception for each vehicle classes. For example, the first line of table 6 compares the level of involvement in supermini 90's to supermini 80's: the risk of being responsible for injury accident is reduced by 9% [4% ; 14%] for drivers of supermini 90's. None significant results are shown by a star (*).

Table 6.
Benefits in involvement. Comparison between two decades for the same class.

	1990s vs 1980s		
	Benefits	CI low	CI high
Supermini	9%	4%	14%
Small familly car	9%	1%	16%
Large familly car	13%	4%	21%
Executive	6%*	-8%	19%
Mpv	28%*	-1%	49%
	2000s vs 1990s		
Supermini	12%	7%	16%
Small familly car	24%	19%	29%
Large familly car	22%	15%	29%
Executive	32%	22%	41%
Mpv	9%	1%	16%
	2000s vs 1980s		
Supermini	19%	14%	25%
Small familly car	31%	24%	37%
Large familly car	32%	24%	39%
Executive	37%	25%	46%
Mpv	34%	8%	53%

Concerning the accident involvement, Supermini class, small and large family car classes respectively decreased by 9 and 13% from 90's to 80's. The other class differences are not statistical relevant for 80's to 90's comparisons. The accident involvement is lower in 2000's than 90's with a decrease of 12 to 32% according to the classes. The overall accident involvement decrease fluctuates from 19 to 37% between 2000's and 80's passenger cars according to the respective classes.

For comparison of classes within the 1980 decade, no accident implication difference is shown between the classes. In 90's classes, an under-involvement of the Mpv and an over-involvement of executive and small family cars compared to supermini are observed. In 2000's classes, an under-involvement of the Mpv and large family car classes compared to supermini class is observed.

Protection and involvement in accident

The figure 4 allows showing simultaneously the results in terms of adjusted Odd ratios for protection and involvement. Each class and decade is compared to supermini 90's.

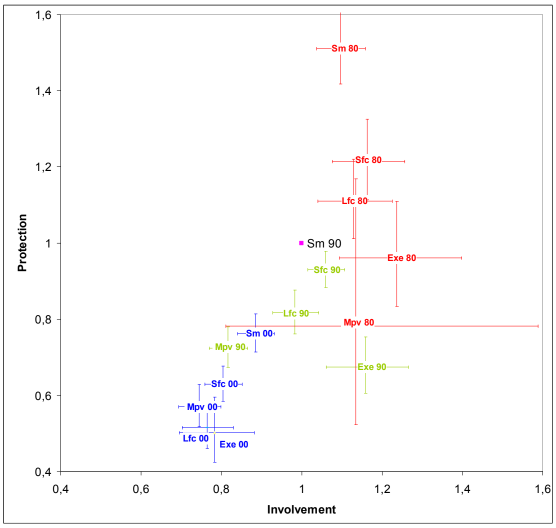

Figure 4. Involvement and protection of the light vehicle according to the class and the decade of conception.

On this graph, the important decrease of the risk of being fatally or severely injured between cars of the 1980's and the 1990's is observable. Between these two decades the decrease regarding involvement is less important. And important decrease in the risk of being fatally or severely injured and in involvement between 1990's and 2000's is revealed.

The maximum protection benefits are observed between the supermini class 1980s and the executive class 2000s with 67% [60%; 72%]. According to the involvement the maximum benefits is observed between executive of the 1980's and the Mpv of the 2000's 40% [31%; 48%].

DISCUSSION

Our study concerns 3 years of accident observation from 2007 till 2009, thus we benefit from a period of homogeneous observation, with the same road safety policy and the same infrastructure characteristics.

On the other hand, this approach does not allow taking into account vehicle use which can be different between a recent vehicle and a vehicle of more 20 years of age. Although this was partially taken into account in the logistic regression, we are not certain about completely erasing use biases because we do not have all the characteristic variables of the vehicle use.

In collisions between two vehicles, a recent vehicle has a strong probability to come up against an older vehicle than him (due to the average age of the park: 8 years). The older vehicle will have not the same crashworthiness as the recent one, favoring the injury balance in the recent vehicle.

The BAAC counts only accidents with at least one injured person. Our indicator is thus an indicator of the involvement in injury accident and not the involvement in damage only accident.

Accident involvement can't come down to active safety and accident severity to passive safety. Active safety could play a role in the crashworthiness by changing the crash configuration and consequently changing the accident severity such as ESC could do. Moreover, the passive safety plays a role with the restraint systems by providing a protection that could shift from an injured accident to property damage accident.

Note that the sample is mainly made up of European passenger car models.

CONCLUSION

This study highlights the downward trends of the accident involvement and the crash severity for the new passenger car generations (2000-2009). One explanation could be the great development of the crashworthiness and active safety devices fitted in these passenger cars. Car manufacturers have engaged a lot of energy to reach this level of safety. The consequence is obvious with the decrease of the number of injured accidents or their severity when the crash was not avoided.

Severity decreased 23 to 30% when the 90's passenger cars are compared to 80's passenger cars. Identical is the decrease when 2000's passenger cars are compared to 90's passenger cars (21 to 37% according to the vehicle groups).
The overall decrease is 48 to 54% according to the vehicle class between 2000's and 80's passenger cars. Note the crash severity differences between supermini class and executive class are constant through the decades (36-33-34% saved respectively).

Concerning the accident involvement, supermini class and large family car class respectively decreased of 9 and 13% from 90's to 80's. The other class differences are not statistical relevant. The accident involvement is lower in 2000's cars than in 90's cars with 12 to 32% according to the classes. The overall accident involvement decrease is evaluated between 19 and 37% for 2000's compared to 80's passenger cars according to the respective classes.
Comparing the classes, no accident implication difference is shown when the passenger's car classes are evaluated within the 80's. In 90's

classes, an under-involvement of the Mpv and over-involvement of executive and small family car classes compared to supermini class are noticed. In 2000's classes, an under-involvement of the Mpv and large family car class compared to supermini class is observed.

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Improving the Safety Performance of Australian Vehicles – a Consumer Focused Approach

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ABSTRACT
In the late 1990s, despite having an excellent new car assessment program (ANCAP) and a Used Car Safety Rating program which assesses vehicles safety performance in the real world, very few car buyers in Australia were aware that information was available to help assess a vehicle's safety performance. Even if consumers were aware of the information, compared with Europe and the US, choosing a vehicle with good safety performance usually meant buying an expensive import.

In 2000, the Transport Accident Commission in Victoria, Australia, noting European estimates of reductions that could be expected in road trauma if the safety of the vehicle fleet could be substantially improved, made a decision to invest heavily in a public education (demand led) approach to improving vehicle safety. Off the back of the development of a searchable website on vehicle safety, the TAC launched the howsafeisyourcar.com.au public education campaign – which urged car buyers to consider safety as their number one criteria when purchasing their next car. The campaign including TV and radio ads, print, on-line and outdoor media, has been successful in it's aim of increasing consumer knowledge about vehicle safety and encouraging manufacturers to make safer vehicles available to the Australian market. This paper will map the development of this campaign and present the results of Victoria's consumer led approach to vehicle safety.

INTRODUCTION
In the late 1990's Australian states became aware of the importance of vehicle safety in the mix of initiatives designed to reduce road trauma. Despite its developed economy and love of the motor car, Australian vehicles where on average (based on star ratings) far less safe than those of Northern Europe and North America. Australia had a well developed crash test program, the Australasian New Car Assessment Program (ANCAP) and a unique to Australia Used Car Safety Rating program (UCSR), yet Australian car buyers had little awareness of these ratings programs or vehicle safety issues.

The Transport Accident Commission (TAC) works with its road safety partners Victoria Police, VicRoads and Department of Justice to reduce the number and severity of injury crashes in Victoria, Australia. The TAC was recognised for its internationally for its public education campaigns about issues such as drinking and driving, non-restraint wearing and fatigue. Noting European estimates of the benefits of a safer vehicle fleet and the success of agencies in the US in promoting vehicle safety, the TAC believed that it could use social marketing techniques to educate Victorian car buyers that vehicle safety should be high on their list of priorities when purchasing a car., that they deserved vehicles as safe as those being offered to their European and American counterparts and in turn consumers would create a demand for safer vehicles in the Victorian and Australian vehicle markets.

BACKGROUND
During the late 1990's, Victoria was fortunate to have an architect of Sweden's 'Vision Zero' (Claes Tingvall) join the Monash University Accident Research Centre (MUARC) as its Director. 'Vision Zero' was a new philosophy to most Australian Road Safety practitioners and introduced the idea that improving the safety of the vehicle fleet could substantially reduce the number and severity of injury crashes.

Victoria had been a leader in road safety. It was the first state in the world to introduce compulsory seat belt wearing law in 1970, the first jurisdiction in the world to have random road side breath testing via booze buses (1989) and later, the first jurisdiction to introduce random road side drug testing (2005). It had developed internationally acclaimed public education campaigns addressing drinking and driving (If you drink, then drive, you're a bloody idiot) and Speed (Speed Kills)[1], had a well developed road safety infrastructure (Blackspot) program and well resourced police force. As a result it had a good long term record in reducing road trauma[2].

Yet, it was Claes Tingvall who brought to Victoria's attention the potential that improving the safety of its vehicle fleet could have in reducing trauma. Tingvall during his time at MUARC often quoted a simple European Transport Safety Council (ETSC) statistic, which indicated that if you could move everybody to the safest vehicle in their class, serious road trauma (in Europe) could be halved. Given the average age of vehicles was less and safety performance of vehicles greater in Europe, this was likely to be true for Australia also.

At this time Australia had a range of information available to car purchasers. The Australasian New Car Assessment Program (ANCAP) was well established and used results from both its own tests and EuroNCAP tests on vehicles applicable to the Australian market. Monash University Accident Research Centre (MUARC) based on police crash data from across Australia and New Zealand, had developed a well regarded Used Car Safety Ratings program (UCSR) that provided relevant safety information to car buyers in the second hand market. These programs were well supported by state Government agencies and the Automobile Associations (AAs) across Australia. Despite this, it was believed that Victorian car buyers:

- had very little awareness that there was information that could assist them purchase a safer vehicle
- were no sure where to obtain safety information and
- did not rate safety highly in their car purchase decisions.
-

Research undertaken subsequently supported this view (see below).

The TAC, at this time was not a member of ANCAP or the UCSR program, but had considerable expertise in social marketing (road safety). The TAC (Transport Accident Commission) is Victoria, Australia's (monopoly) third party vehicle insurer for transport injury. A quasi government authority, the TAC is responsible for the medical, rehabilitation and loss of earnings costs for all Victorian's injured in a car crash. The Transport Accident Act 1986 (TAA), established the TAC scheme and guides its business. Two objects of the TAA support its involvement and heavy investment in road safety:

- to reduce the cost to the Victorian community of compensation for transport accidents; and
- to reduce the incidence of transport accidents.

The TAC identified the potential for a well designed, high quality website that would pull together ANCAP and UCSR data as well as other vehicle safety information. The website would be promoted via a mass media campaign. Around this time the TAC became aware of websites in the US promoting vehicle safety ratings eg Money.com (safestcars website), the IIHS website, that seemed to be gaining good visitation.

Very little was known about Victorian or Australian car buyers understanding of new vehicle crash tests, vehicle star ratings or particular vehicle safety features. Certainly, the only manufacturers promoting their vehicles on safety in their own advertising campaigns were major European brands such as Volvo and Mercedes. Initial searches looking at vehicle advertising internationally indicated that even where the car models being sold in Australia were the same as in Europe and/or North America, they were not being marketed in the same way. An example was the Subaru Forester first sold in the US in 2000 and Australia in 2001; the US model came standard with ESC and was marketed on being a safe family car. The Australian model didn't have ESC and was promoted primarily on its boxer engine! It was common for models being imported into Australia to have fewer standard safety features and in some cases they couldn't be ordered, even though they were available on the same models elsewhere in the world.

The TAC also noted that many manufacturers were actively, avoiding use of any star ratings on their vehicles. When Renault Australia decided to promote its new Laguna's 5 star (EuroNCAP) rating, it was apparently meet with disapproval from the Federal Chamber of Automotive Industries (FCAI) who represented many car makers and importers in Australia[3]

In 2001/2002, the TAC worked with its road safety partners, VicRoads and Royal Automobile Club of Victoria (RACV) to better understand Victorian car buyers' knowledge and interest in vehicle safety by undertaking some initial research (TAC[4] and RACV[5])

Using this research, the Victorian road safety partners were able to develop a strategy to improve the safety of the Victorian vehicle fleet, a large part of which was the marketing strategy developed by the TAC.

INITIAL CONSUMER RESEARCH

Market research undertaken for the TAC by Sweeney Research[6] in early 2002 interviewed people who intended to purchase a car in the next 12 – 18 months. The research indicated that in relation to car purchase decisions:

- price was the dominating factor
- comfort, brand, size and colour all entered into the purchase equation
- safety did not feature highly in their vehicle purchase criteria, particularly those buying at the lower price end of the market.
- few were aware of how they would evaluate a car in terms of safety
- car buyers assumed new cars, because they commonly had ABS and driver airbags were safe (although many had the belief that airbags were dangerous because they could 'go off' prematurely).
- while few had heard of ANCAP or were aware of vehicle safety star ratings, they were aware that the RACV was a good place to start for information.
- almost nobody had heard of the UCSR program
- the main safety features of interest were ABS brakes, driver visibility, body weight (so you aren't blasted off the road when a truck passes), body/impact strength an driver airbags.
- it was important the information came from a credible source (motoring journalists and the RACV were considered credible in the vehicle safety space) and TAC had strong credibility in the road safety space.
- a website about vehicle safety was considered well within the TAC's charter.

Consumers indicated that they would be interested in getting more information about vehicle safety but would not spend much time researching i.e. safety information needed to be easily accessible.

Most people were interested in online information and wanted a one stop shop i.e. new car, used car and other vehicle safety information on the one site. They wanted information to be provided in a searchable form and from an authoritive organisation (TAC and RACV were considered credible). At this point most of the information produced by ANCAP and the UCSR program was in brochure form. Some auto clubs and road safety agencies had information available on their websites but it could be difficult to find and awareness of its availability was low.

The Consumer Led Strategy
The TAC strategy was simple

- Develop a website that helped consumers make informed choices about the safety of the vehicle they were about to purchase; and
- Develop a public education program that urged Victorians to consider safety in their next vehicle purchase.

By encouraging consumer demand for safer cars, the TAC hoped to push manufacturers to develop/import safer cars for the Victorian / Australian market, which in turn consumers would be more amenable to buy

Following a competitive process, a Sydney based agency advertising and multimedia agency, The Moult, was engaged to develop the vehicle safety website and supporting media campaign.

The howsafeisyourcar.com.au brand, website and public education campaign was born.

THE CAMPAIGN

The Website
A far more complex task, than originally envisaged. It was necessary to negotiate with three different suppliers of data, the web development team and advertising agency.

The TAC was not a contributor to the ANCAP or the UCSR programs. To gain the support for the howsafeisyourcar.com.au site development, it was agreed that the site would:

- not be branded by the TAC.
- acknowledge all the contributors to these programs
- be available to financial contributors to the ANCAP and UCSR programs free of charge

It was also agreed that contributors to the ANCAP and UCSR programs would have use of the creative material developed to promote the site free of charge.

When launched, the site provided safety ratings for over 80% of the vehicles on Australian roads built post – 1990.

The TAC recognising, that changing demand patterns amongst Victorian car buyers alone would not be sufficient create the demand required to push vehicle manufacturers to provide and promote safer vehicles Victoria accounted for around 27%[7] of new passenger car sales at this time (2002), but vehicles were being manufactured/imported for the entire Australian market. By offering use of the, howsafeisyourcar.com.au website and promotional materials to other road safety agencies across Australia free of charge, there was a greater chance for consumer demand to increase and for the TAC's strategy to be successful.

Market research drove the look and feel of the site. Black and yellow, as well as the image of crash test dummies were considered to be instantly recognisable as being associated with safety. The brand 'howsafeisyourcar' was chosen from a long list of suggestions, such as 'driveasafecar' and 'buyasafecar' because it offered a challenge to consumers; it was personally relevant and related more to promoting vehicle safety than vehicle purchase.

The Mass Media (support) Campaign

If car buyers were to demand safer vehicles, it was important that the argument for them to do so was compelling. Given safety was not often on car buyers criteria list, maximum persuasion was required to get it there.

A simple, low cost, TV advertisement, showing an ANCAP crash test with a voice-over asking consumers about what was important in buying their next car (colour, imported wheels, cup-holders)? or how it performed in a crash? was developed. Along with radio and press advertisements, outdoor advertising (billboards) and public relations activity the howsafeisyourcar.com.au website and campaign was launched in June 2002.

The campaign was launched with high media purchasing weights and gained good local media coverage. Public relations helped considerably, with manufacturers relatively negative view about the TAC's efforts to promote vehicle safety, creating media interest and helping to keep the public interested As hoped, thousands of visitors flocked to the site to see the rating of their current car. A common complaint for early visitors to the site was that they couldn't find their car. Usually this was because it was a fairly uncommon, imported vehicle such as an Aston Martin or Lamborghini. The frequently asked questions, section of the site was greatly expanded in the first few weeks of the site going live, with the range of questions being sent through the site helping to refine content and the TAC understand the areas of interest for the Victorian motorist.

Since 2002, the TAC has continuously refined and updated the howsafeisyourcar.com.au site and promoted the site and vehicle safety issues more generally. To December 2010, six TV campaigns and a range of press, radio and outdoor support advertising has been undertaken to promote the site. The later three campaigns (from 2007) have concentrated on the promotion of specific vehicle safety features – side curtain airbags and electronic stability control systems (subject to another paper at this conference).

On-line advertising, on car sales sites and sponsorship of major events, where interest in vehicle safety is likely to be high eg Melbourne Formula 1 Grand Prix, the Melbourne Motorshow, the Baby and Toddler Expo have also become a major channels for promoting the website and vehicle safety.

The Campaign Outcomes

There are several measures that are used to track the success of the campaign in Victoria. On an annual basis the TAC undertakes an extensive survey of road user's self reported behaviours and attitudes to key road safety issues. The TAC's annual Road Safety Monitor explores those criteria consumers consider the most important when purchasing a new car, e.g. price, safety, make and model. In 2001 when the survey was first conducted, safety was rated as fifth (unprompted) on the list of most important features. In the 2004, safety had been elevated and was rated second behind price. From 2005 – 2010; safety remained as the 2nd or 3rd most important criteria in vehicle purchase with fuel economy entering the picture as 2nd during the recent economic downturn. Awareness that information about vehicle safety exists has increased slightly, and awareness of the HSIYC website (unprompted) has increased from 1% (2002) to 10% (2009) and prompted from 25% in 2004 to 47% in 2009.

Whilst a shift in consumer attitude and awareness of safety has shifted positively, a shift in the average safety of new vehicles sold in Australia has also been observed. From 2001 to 2009 a 38 per cent increase in the average points awarded in vehicle crash testing was observed (i.e., from 21.2 to 29.4.). The average star rating over this time period has increased from 3.5 stars to 4.5 stars.

Visits to the site have steadily increased over the years with between 15, 000 and 35,000 unique visits to the site now being achieved per month. Peaks of around 35,000 occur during heavy advertising periods and during events such as the Melbourne Formula 1 Grand Prix. Given other Australian jurisdictions (Tasmania and Northern Territory and very recently Queensland) link and or promote the site; it is difficult to ascertain exact Victorian visitation.

Vehicle manufacturers are now more interested in marketing vehicle on their safety performance with most now promoting the ANCAP (star) rating for their vehicles. The press is now far more interested in vehicle safety, motoring journalists commonly report if vehicles don't achieve a good star rating in crash testing and ANCAP ratings are commonly supplied as part of car reviews and on car sale sites eg carsales.com.au[8] and the media is very interested when new cars perform badly in crash tests.

Most importantly, road trauma has continued to reduce substantially, with Victoria recording its lowest road toll on record in 2010 with 287 people killed, down from 397 in 2002 when the howsafeisyourcar.com.au site and campaign was launched. While this result was the outcome of a range of aggressive road safety initiatives, there is no doubt that, the Victorian passenger vehicle fleet is far safer than it was a decade ago, that Victorian consumers are more aware of vehicle safety in terms of their purchasing decisions.

CONCLUSION

The TAC set out to put vehicle safety on the map in Victoria, Australia. Developing a high quality website, it promoted the site and vehicle safety more generally through a mass media campaign. The TAC considers the howsafeisyourcar.com.au campaign to have successfully achieved its aims with Victorian car buyers now far more aware of vehicle safety issues and the safety performance of new vehicles is far greater than they were when the program launched in 2002.

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HOW USEFUL ARE THE TWO CHILD DUMMIES IN THE REAR SEAT OF NCAP TESTING?

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ABSTRACT

This study aimed to investigate the utility of the responses of the two child dummies (P1.5 and P3) that are placed in the rear seat, in identical forward-facing child restraints during frontal Australian NCAP (ANCAP) tests.

Dynamic responses of the two child dummies, vehicle crash parameters, and frontal dummy responses were extracted from the ANCAP report database for 35 frontal crash tests. Linear regression analysis was used to assess: the similarity between the two dummies' responses; variation between frontal dummy responses; and relationships between the child dummy responses and other measured crash parameters.

Dynamic responses from the P1.5 and P3 dummies were highly correlated with each other, including head accelerations, neck forces, and chest accelerations ($p<0.0001$ for all, $0.4 < R^2 < 0.6$). Variation between the two rear-seated child dummies was substantially less than between the driver and front passenger dummies. The child dummies' head and chest accelerations were correlated to vehicle b-pillar deceleration ($p\leq0.01$ for all), but not to vehicle mass, vehicle class, or other crash parameters ($p>0.05$ for all).

Unlike the two front-seated occupants, where the dummies provide different information about the vehicle's safety performance, the two rear-seated child dummies in child restraints are providing essentially duplicate information. Head excursion of the dummies is not measured in the current ANCAP test protocol, and this may be a more sensitive and meaningful assessment of child restraint occupant serious head injury risk. Only 35 vehicles were included in the analysis, and data on some variables (including neck moments, and harness and top tether payout during testing) were not recorded in all tests.

These results suggest that using two child dummies in forward-facing child restraints is not providing significantly more information than could be gleaned from a single child dummy in a forward-facing child restraint. This suggests that one of these child dummies could be usefully replaced with an alternative dummy representing an older rear seat occupant, without loss of information on a vehicle's ability to protect child-restraint users. Possibilities for such a replacement occupant include a 10 year old child dummy using the lap-sash seatbelt (as is being trialed in Japan NCAP tests), a booster-seated 6 year old dummy, or a small female occupant. Any of these options would provide additional information on vehicle safety performance than is currently being reported in most NCAPs.

INTRODUCTION

While the majority of vehicle design and regulation has focused on front seat occupants, a number of recent studies have indicated that the protection provided to rear seat occupants is declining relative to the front seat (Esfahani and Digges, 2009, Kent et al., 2007, Bilston et al., 2010). However, this interest in rear seat occupant protection has not translated into consumer crash testing programs or regulations around the world.

The effectiveness of existing protective systems for rear seat occupants such as seat belts is influenced by occupant anthropometry. Huang and Reed (2006) analysed the National Automotive Sampling System General Estimates System (NASS-GES) for the years 1999-2002, and found that approximately 50% of rear seat occupants in that sample were over 12 years old and 30% over 18 years of age. Bilston and Sagar (2007) used data from the 2005 US National Occupant Protection Use Survey (NOPUS) and reported that occupants over 16 years of age made up approximately 33% of all rear seat occupants.

A rise in the number and type of safety systems available to front seat occupants has been observed since the mid 1990's (Beck et al., 2009). Apart from the inclusion of lap-shoulder belts in all seating positions in most new model vehicles and the presence of rear curtain airbags, little else has changed for the rear seat occupant. This means that front seat occupant protection has improved more than for rear seat occupants. Studies have suggested that the front seat is now substantially safer than the rear seat for older adult occupants (Esfahani and Digges, 2009, Kuppa et al., 2005). This was supported by a matched-cohort analysis of belted front and rear seat occupants that suggested that the front seat is now safer than the rear seat for occupants over the age of 15 (Bilston et al., 2010). The latter study also reported that the benefit of rear seating for children aged 9-15 years has decreased over time.

Consumer tests such as the New Car Assessment Program (NCAP) exist to assess the protection available to front seat occupants, with improvements reflected as increasing performance scores over time (NHTSA, 2009). The first NCAP to provide consumers with vehicle safety ratings began in 1979 in the USA, and there are now similar programs run in 6 regions including North America, Europe, Australasia, Japan, Korea and China.

The Australasian New Car Assessment Program (ANCAP), based on the US testing program, was initiated in 1992. Then in 1999, ANCAP harmonized with EuroNCAP. Occupant protection is assessed through a number of crash tests, including a 64km/hr (40mph) offset frontal impact, a 50km/hr (30mph) side impact and a 29km/hr (18mph) pole impact. However, there remain several differences between ANCAP and EuroNCAP, including that while ANCAP includes two child dummies (P1.5 and P3) in forward-facing child restraints for the offset and side impact tests, no performance requirements exist for these dummies in the scoring. This is due to the differences observed between the two test programs for both child restraint design and tether locations, and also concern among Australian experts about the validity of the EuroNCAP child injury assessment criteria (Paine and Griffiths, 2002). In Australia, there is a separate consumer rating program for child restraints known as CREP (Brown et al., 2007), which is based on sled tests and therefore does not assess vehicle performance.

The Japanese New Car Assessment Program (JNCAP) began including the Hybrid III 5th percentile adult female (5th%F) in the rear seat in in 2009. The Hybrid III 5th%F is also used in the rear seat of both the full-frontal impact test and the offset frontal impact test as part of the Chinese New Car Assessment Program (C-NCAP). Mizuno et al. (2007) reported on full-width rigid barrier tests using the Hybrid III 5th%F and the Hybrid III 3 year-old (3YO) restrained in a child restraint in the rear seat. Time-history curves of chest and head accelerations showed good differentiation between the two dummies. NHTSA has also conducted tests using adult dummies in the rear seat of full frontal rigid barrier impacts for research purposes. The tests used the Hybrid III 50th percentile adult male (50th%M), Hybrid III 5th%F both restrained in lap/shoulder belts, and the Hybrid III 6 year-old (6YO) restrained in a booster seat. The rear seat dummies recorded higher head, neck and chest injury values than the front seat occupants (Kuppa et al., 2005). Another study involved the Hybrid III 10 year-old (10YO) in the rear seat of 28 NCAP tests with rear seat dummies showing higher head injury values than those in the front seat (Hong et al., 2008). Transport Canada conducted a study into rear seat occupant protection in full frontal rigid barrier tests and frontal offset tests using the Hybrid III 5th%F, Hybrid III 10YO and Hybrid III 6YO. Chest deflection, 3 msec chest clip and both lap and shoulder belt loads measured in the rear seat dummies were consistently higher than those in the front seat, with all but one test showing penetration of the lap belt into the dummy abdomen (Tylko and Dalmotas, 2005).

In this study, we hypothesized that the two child dummies used in the rear seat of ANCAP (and EuroNCAP) tests are not providing independent information on vehicle performance. If this is the case, it suggests one of these child dummies could usefully be replaced with an older dummy (e.g. 5th percentile adult female or 10 year old child) in the rear seat. This would allow more complete assessment of the rear seat safety systems.

METHODS

In the ANCAP offset frontal impact, vehicles are tested with two adult crash test dummies in the front seat and two child dummies in the rear seat. The child dummies used are the TNO P1.5 and P3, representing children aged 18 months and 3 years old. The P3 is seated behind the driver while the P1.5 is seated behind the front passenger, with the dummies in identical forward-facing child restraints. The same model restraint is used in each test.

Dynamic responses (head accelerations, HIC 36, chest accelerations, axial neck forces) of the two child dummies, vehicle and crash parameters (vehicle type, vehicle mass, b-pillar acceleration), and front seat dummy responses (head accelerations, HIC 15, HIC 36 and chest accelerations) were extracted from the ANCAP report database for 35 offset frontal impact tests (SUVs, passenger cars, people movers). Linear regression analysis was used to assess: the correlation between the two child dummies' responses; correlation between the driver and front passenger responses; and relationships between the child dummy responses and other measured crash parameters.

RESULTS

Comparisons were made between the output of both the P3 dummy and P1.5 dummy seated in the rear in identical child restraints. The head injury criterion measure (HIC36) showed significant correlation between the child dummies ($p<0.0001$). This was also observed for head acceleration in the Z direction (vertical from the crown of the head) and resultant head and chest accelerations ($p<0.0001$ for all) (see Table 1).

Table 1.
Correlation between rear seat P1.5 and P3 dummy measurements

Variable	P-value	R^2
HIC36	<0.0001	0.51
Head Acceleration Z	<0.0001	0.45
3ms Resultant Head Acceleration	<0.0001	0.47
3ms Resultant Chest Acceleration	<0.0001	0.48

A similar analysis was conducted for the dummies seated in the front seat – a Hybrid III 50th% adult male in both the driver and passenger position. Unlike the child dummies, the recorded values from front seat dummies showed no significant correlation. The linear regression results are shown in Table 2.

Table 2.
Correlation between driver and front passenger Hybrid III 50th percentile male dummy measurements

Variable	P-value	R^2
HIC36	0.26	0.039
3ms Resultant Head Acceleration	0.49	0.014
3ms Resultant Chest Acceleration	0.26	0.039

Figure 1 and Figure 2 show comparisons of HIC36 for the child dummies seated in the rear seat and the adult dummies seated in the front seat. Cases were ranked in order of increasing crash severity as measured by the B-pillar acceleration. The comparison of HIC36 for the P1.5 and P3 dummies showed good correlation (as per Table 1) with R^2=0.51. This in contrast to that shown in Figure 2 where the adult dummies in the front seat showed little correlation to each other (R^2=0.040). It is observed that there is only a small change in the passenger HIC36 for large changes in driver HIC36.

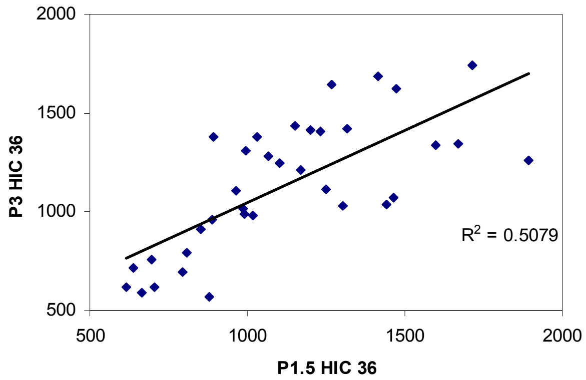

Figure 1. Comparison of HIC36 for P1.5 and P3 child dummies

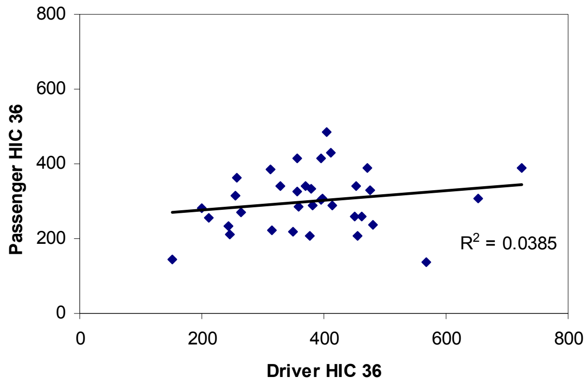

Figure 2. Comparison of HIC36 for driver and passenger dummies

Individual dummy measurements were then correlated with crash variables.
Measurements from the rear seat dummies showed no significant correlation to vehicle type or vehicle mass ($p>0.05$ for all, p-values and correlation coefficients are shown in Table 3).
There were significant correlations between b-pillar acceleration and HIC36, peak head accelerations and chest accelerations for both dummies, although the correlation was marginal for the P3 HIC 36 (see Table 3). The neck forces were not significantly related to b-pillar acceleration.

Table 3. Correlations between individual dummy measurements and crash variables.

P3								
Variable	HIC36		Peak Head Accel		Chest Accel		Fz	
	p-value	corr. coefft	p-value	corr. coefft	p-value	corr. coefft	p-value	corr. coefft
B Pillar Acceleration	0.052	0.109	0.008	0.2	0.003	0.237	0.268	0.037
Vehicle Type	0.256	0.036	0.077	0.083	0.069	0.083	0.895	0.001
Vehicle Mass	0.308	0.029	0.981	0	0.681	0.004	0.177	0.056

P1.5								
Variable	HIC36		Peak Head Accel		Chest Accel		Fz	
	p-value	corr. coefft	p-value	corr. coefft	p-value	corr. coefft	p-value	corr. coefft
B Pillar Acceleration	0.013	0.181	0.024	0.151	0.008	0.205	0.518	0.013
Vehicle Type	0.612	0.007	0.984	0.000	0.553	0.009	0.907	0.000
Vehicle Mass	0.942	0.000	0.564	0.009	0.560	0.009	0.366	0.026

DISCUSSION

The key finding in this study is that the child dummies in the rear seat of ANCAP frontal offset tests have highly correlated dynamic responses. There is also a strong relationship between the child dummy responses and the b-pillar accelerations, but no relationship to vehicle type or mass. These results indicate that, unlike the driver and passenger responses, the two child dummies do not provide independent information about vehicle safety performance. Furthermore, the child dummies largely reflect the transmitted vehicle acceleration, rather than providing detailed information about occupant protection offered by the vehicle.

The correlations between the two child dummies in forward-facing child restraints (R^2 values of 0.45-0.51 for all measurements) indicate that the results from one dummy can account for approximately 70% of the variance in the other dummy. This is in contrast to the variation observed between the driver and front passenger adult dummies where there was no correlation. Since the two child dummies in child restraints are providing essentially duplicate information, if ANCAP were to replace one of these child dummies, critical information about the performance of child restraints in the vehicle would not be lost.

North American vehicle occupancy data has shown a wide distribution of rear seat occupant age, with approximately a third being 18 years or older (Huang and Reed, 2006). These numbers indicate a wide variation in rear seat occupant anthropometry and hence the need to assess the safety provided to rear seat occupants beyond forward-facing child restraint occupants, as currently done by EuroNCAP.

JNCAP, NHTSA, Transport Canada and others have experimented with various dummies in the rear seat of full-scale vehicle crash tests. Comparisons between front and rear seat dummy Injury Assessment Reference Values (IARV) showed significantly higher values for rear seat dummies (Hong et al., 2008, Tylko and Dalmotas, 2005). In those studies however, comparisons between rear seat dummies (where applicable) were not made. Kuppa et al. (2005) reported on normalized injury values for rear outboard and center seating positions, but no significant differences between seating positions were observed. The results presented in this study showing significant correlations between rear seat dummy measurements and B-pillar acceleration are supported by Morgan (2003) who reported on child dummy measurements and child restraint performance in NCAP tests. That study showed significant correlation between the Hybrid III 3 year-old chest acceleration and the peak acceleration of the vehicle. This is not particularly surprising since IARVs should increase with crash severity. However, the relatively small amount of variance observed between vehicles tested in offset frontal impacts suggests that for child restraint occupants, the vehicle design itself is mostly affecting injury outcomes by altering the acceleration transmitted to the rear of the vehicle (as measured at the b-pillar). This is a reflection of the structural design of the front end of the vehicle (at least for frontal crashes studied here). Therefore, both this study and the Morgan (2003) study suggest that the two child dummies in child restraints are providing only modest additional performance information over and above the b-pillar acceleration.

The introduction of an older rear seat occupant, such as the Hybrid III 10 year-old or Hybrid III 5th percentile female would make minimal difference to the cost of NCAP tests, but would provide additional information on vehicle safety performance to that currently being reported in most NCAPs. Restrained older rear seat occupants have been shown to have no effect on front seat dummy measurements (Mizuno et al., 2007). The results from this study suggest that ANCAP might gain more vehicle performance information at a similar test cost if one of the child dummies in a child restraint was replaced with an older dummy in a lap-sash seat belt.

Limitations of this study include that only 35 vehicles were included in the analysis, and data on some variables (including neck moments, and harness and restraint top tether payout during testing) were not recorded in all tests, precluding their inclusion in the regression models. Head excursion of the dummies is not measured in the current ANCAP testing protocol, and this may be a more sensitive and meaningful assessment of serious head injury risk in child occupants.

CONCLUSION

The results from this study indicate that, unlike the two front seat occupants, where the dummies provide independent information about the vehicle's safety performance, the two rear seat child dummies in child restraints are not providing significantly more information than could be gleaned from a single child dummy in a forward-facing restraint. This provides scope to include an older adult occupant in the rear seat of NCAP frontal crash testing to provide additional information on vehicle safety performance.

ACKNOWLEDGEMENTS

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REAR OCCUPANT PROTECTION JNCAP TEST
– TEST RESULTS AND FINDINGS –

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Paper Number 11-0445

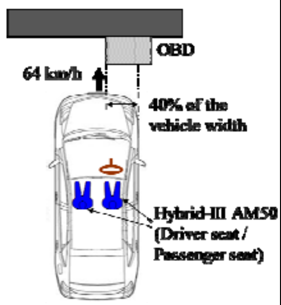
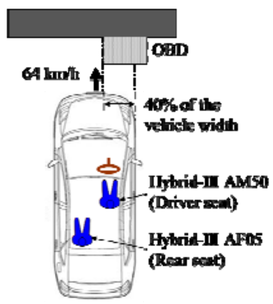
ABSTRUCT

Since its start in 1995, Japanese New Car Assessment Program (JNCAP) has conducted full-wrap frontal collision test (since 1995), side collision test (since 1999) and offset frontal collision test (since 2000), aiming for enhancing collision safety performance for drivers and front seat passengers. Safety performance of rear seat passengers had long been outside the scope of evaluation in JNCAP; however, as it became mandatory in 2008 for rear seat occupants to wear a seat belt, and the seat belt wearing rate has begun to improve, the safety assessment for rear seat occupants with seat belts has increasing its significance.
Under the above circumstances, JNCAP has amended the protocol of offset frontal crash test and introduced occupant protection methods for rear seat passengers in 2009. We adopted Hybrid III AF05 (female dummy) in rear seat instead of AM50 (male dummy) in front passenger seat, considering that women are more likely to become the rear seat occupant. And JNCAP developed its own rear seat dummy evaluation method referring to the FMVSS208[1] and new US-NCAP[2].
JNCAP has publicized this unique test result of 11 models so far. As this is a relatively new method, we have experienced some difficulties in evaluating safety performance of rear seat occupants accurately. In this paper, we will provide the latest results and findings during our experience in the rear occupant protection JNCAP tests.

OUTLINE OF REAR SEAT OCCUPANT PROTECTION PERFORMANCE EVALUATION

In an effort to improve the performance of rear seat occupant protection based on the results of the new car assessment program, JNCAP changed in 2009 the position of the dummy from the passenger seat so far used to the rear seat (passenger's seat side). It also changed the male adult dummy for a female adult dummy (Hybrid-III AF05), considering the results of analysis of traffic accidents that, on the rear seat, there were much more female casualties than male. Table 1 shows the outline of the tests, and Table 2 shows injury indicators, sliding scale, and weighting factors used in the rear seat occupant protection performance evaluation in those tests. For the background that led to the introduction of this evaluation and detail, please see paper in the last ESV conference[3].

Table 1. Outline of the offset frontal collision test by JNCAP

From FY2000 to FY2008	From FY2009
	

For the head, evaluation with HIC15 was made only when a secondary collision occurred, considering the fact that, on the rear seat, the occupant's head is very likely to strike at the air. For the neck, evaluation was made in terms of tensile load if there was not any secondary collision. For the abdomen, we could not directly evaluate abdomen injuries with dummies currently available, so, when the decrease ratio of ilium bone load was 1,000 N/ms or more, we assumed that there was an injury caused by the lap belt sliding up from the ilium bone of the pelvis (so called submarine phenomenon) and evaluation to that effect (points deducted).
In calculating the total score, the rear seat occupant's head, neck, chest, abdomen, and lower extremities were first weighted at a ratio of 4:1:4:4:2, based on casualties data for each region of injury and taking into account average human damages for each level of injury. Then, the total score (on a 12-point scale) was calculated by multiplying the score of each region by a factor weighted as above, and evaluated in five-levels.

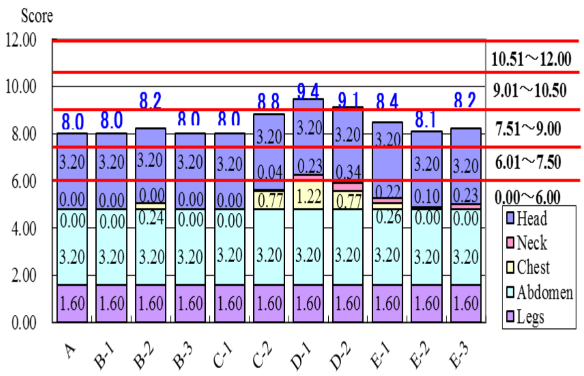
Table 2 Evaluation items, reference values, and weighting in the rear seat occupant protection performance evaluation

Body region	Injury criteria (Lower / Upper)	Score (a)		Modifier	Score (b)		Weight (c)		Weighted score ((a)+(b))×(c)
Head	HIC15* (500 / 700))	4**	+	Hard contact with car interior	-1	×	0.8	=	3.2
Neck	Tension(1.70kN/2.62kN) Shear*(1.20kN/1.95kN) Extension moment* (36Nm/49Nm)	4				×	0.2	=	0.8
Chest	Chest deflection (23mm/48mm)	4				×	0.8	=	3.2
Abdomen	n/a	4***	+	Pelvis restraint condition	Two pelvis: 0 One pelvis: -2 None: -4	×	0.8	=	3.2
Lower extremity	Femur force (4.8kN/6.8kN)	4				×	0.4	=	1.6

*: Calculation is done if secondary hard contact exists. Total: 12 points
**: Without secondary hard contact, 4 points are given by default.
***: 4 points are given by default.

RESULTS OF PAST TESTS AND THEIR TENDENCY

JNCAP published the results of the rear seat occupant protection performance evaluation tests it conducted in 2009 for eleven models of vehicles [4]. Figure 1 shows the result of those tests. Nine models were at Level 3 and two models at Level 4. Looking at the results by region of injury, we can see that the score of the chest injury most influences the level evaluation.
In FY 2010, the Program is conducting tests on fourteen models. While the number of models at Level 4 increased, one model dropped to Level 2. On some models, the head suffered a secondary collision and the pelvis slid up.



(Overall score)

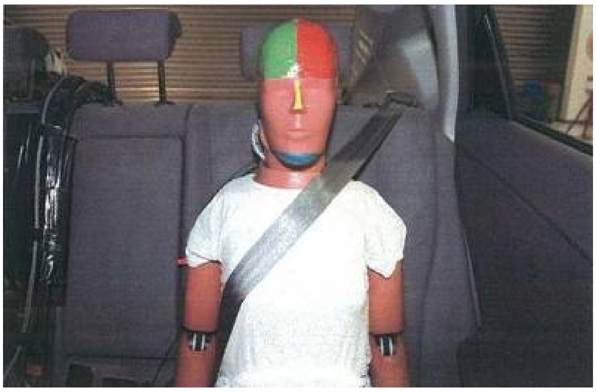
(Chest displacement)

Figure 1. Result of front-collision rear seat occupant protection performance tests in 2009

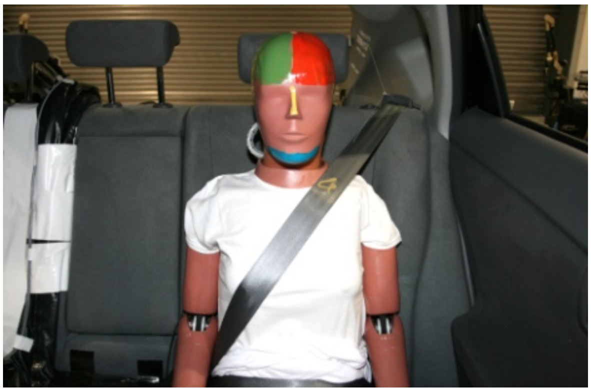
PROBLEMS ENCOUNTERED IN THE TESTS AND EXAMINATION

Influence of the belt path on the chest injury value

One of the offset frontal collision tests conducted in 2009 was done with a belt path for the rear seat occupant dummy set significantly differently from the normal path. According to the test procedure of JNCAP, the belt path was supposed to be set at the designed standard position designated by the vehicle manufacturer. Although there was not any prescription as to the error range, there was a vertical difference of 35 mm between the designed standard position and the actual position at the center of the dummy (between the bottom of the jaw and the center of the belt). The difference of the belt path was visually noticeable, too, as the belt passed through the upper right chest and where it touched the neck (Fig. 2).



(Initial test)



(Retest)

Figure 2. Difference of belt paths

In normal use, it was inconceivable that the belt could take such "a path over the upper right chest." Further, if the belt took such a path, the injury value (chest deflection) would presumably be smaller than when it took other paths, given the structural factors of the ribs of the dummy (fixture of the potentiometer, ribs, etc.). Therefore, after consulting with the vehicle manufacturer, we decided to conduct a retest for this vehicle.

Table 3 shows the results of the initial test and the retest of the test vehicle. As predicted, the initial test showed smaller injury values than the retest, thus confirming that the belt path influences the injury value of the chest deflection.

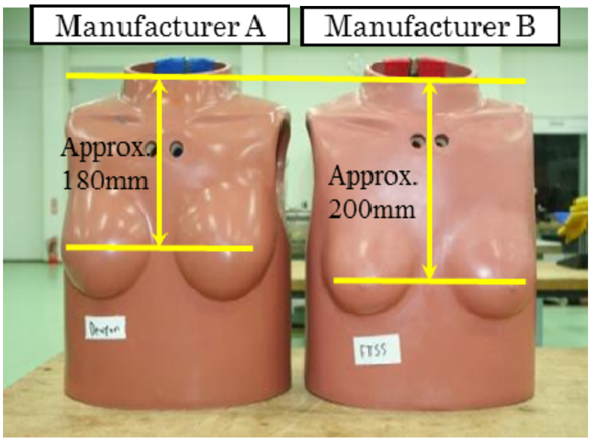
In response to the above examples, JNCAP test procedure for FY 2010 was revised so that the seat belt passed between the breasts, as it was supposed to do in normal use.

Table 3. Difference of test results between the initial test and the retest

		Initial test	Retest
Head	Secondary collision	None	None
	HIC15	584.8	635.2
Neck	Tensile load (kN)	2.61	2.57
	Shearing load (kN)	1.80	1.63
	Extension moment (Nm)	19.02	18.86
Chest	Deflection (mm)	**23.18**	**42.01**
Abdomen	Riding up of seatbelt from pelvis	None	None
Femur load	Right (kN)	0.08	0.10
	Left (kN)	0.07	0.13

Influence of differences among dummy manufacturers

JNCAP conducts its tests using AF05 from two dummy manufacturers. During the examination entailed above, it was found that the form of the chest and the internal structure of the jacket were different between those manufacturers of the dummies used: In addition to the sizes being slightly different, the combinations of the jacket and the dummy's body (ribs, etc.) resulted in different rigidity among dummies. (Fig. 3)



A: material of lower/top part of breast are harder
B: inside of breast is hollow

Figure 3. Difference among dummy manufactures

The difference of injury values between dummy manufacturers had already been the subject of discussion at ISO. A universal specification has not agreed yet, but the two manufactures was collaborated to make the "universal jacket," with which the dummies of each manufacturer verifies the calibration tests. Since the use of this jacket allows it to conduct its tests under the same conditions as to belt path and belt slipping out of the shoulder (see below), JNCAP has conducted its tests with the universal jacket starting FY2010.

SAE is developing the procedure for a test procedure simulating a low-energy collision, namely hybrid III AF05 dummy low-speed thorax impact test. In conducting tests using the above universal jacket, JNCAP conducted calibrations at low-speed thorax test on four cases in the form of reference measurements in FY2010. Table 4 shows the results of those tests.

Table 4. Result of the AF05 low speed thorax impact test

		Test probe velocity	Chest deflection	Thorax force	Internal hysteresis ratio
Specification		3.00+/-0.05m/s	17.4 ～ 21.8mm	1.78 ～ 2.07kN	65 ～ 72%
Case 1	30min	3.01	21.9	1.97	68.9
	24 h	3.03	21.7	1.98	69.1
Case 2	30min	3.03	22.2	1.98	72.3
	24 h	3.00	21.9	1.98	72.6
Case 3	30min	3.03	22.6	1.98	69.6
	24h	3.00	21.8	1.96	70.0
Case 4	30min	3.02	21.5	1.98	71.0
	24h	3.01	22.3	1.99	72.1

*Case 1: Passenger car
Case 2, 3: Light vehicle
Case 4: Minivan

In the calibration procedure, no alteration was made to the dummy to shift from the high-speed side to the low-speed side, leaving the dummy to restore itself.
As to the calibration intervals, in addition to doing the low-speed test 30 minutes after the calibration at high-speed following the provision of the test procedure: “Wait at least 30 minutes between successive tests on the same thorax,” we repeated the test after an interval of 24 hours to check the possibility of different rate of restoration of the dummy over time.
The above calibrations were conducted with the main purpose of calibrating the high-speed side, which aims at the median of the high-speed side. So it would be difficult to strike the balance between high-speed and low-speed calibrations of thorax by the calibration procedure used in the above reference measurement procedures.

Evaluation of the Belt Slipping Out of the Shoulder

In evaluating the rear seat occupant collision protection performance, a high-speed video camera was installed in the compartment at a side of the rear seat occupant dummy in order to check whether or not the dummy had a secondary collision. In tests conducted in FY2009, the behaviors of the rear seat occupant dummy during the crash recorded by the camera revealed that, in more than one case, the seat belt seemed to have slipped out of the shoulder of the dummy.
There were opinions that it was a problem if the seat belt slipped out of the clavicle of the dummy during the test. So, from FY2010 we started checking whether the seat belt slipped out of the clavicle of the dummy during the test.
Since it is difficult for the time being to define the the criteria of slipping out of the seat belt from the shoulder and how to assess it quantitatively, we decided for this year to limit ourselves to assess it based on the video record of the tests. Further, we installed another high-speed camera in upper front of the dummy, for it was delicate to determine whether or not the seat belt slipped out of the shoulder.

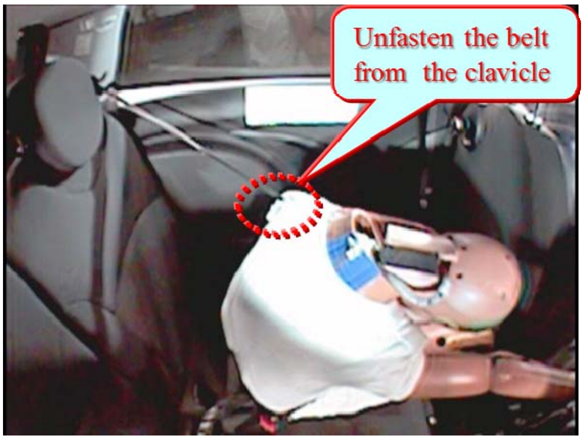


Figure 5. Case where the shoulder belt was judged to be slipped out moved from the clavicle toward the shoulder joint

Figure 6. Case where the shoulder belt was judged to be maintained over the clavicle

In the tests conducted in FY2010, taking into account of the opinions of the experts, we do assessment by checking the test video to see whether or not the seat belt keeps slipping over the clavicle while the head is shaken and also by checking whether or not the shoulder belt moves from the clavicle towards the shoulder joint during the lapse of time between the beginning of the collision and the moment the forward displacement of the head reaches maximum. When it is difficult to determine, we try to judge from a comprehensive point of view taking other factors into account.

Moreover, based on the above consideration, we decided that, if we judged that the seat belt slipped out of the clavicle of the rear seat occupant dummy, we would publish the fact of the seat belt to slip out.

In the future, it would be necessary to develop clearer judgment criteria so that subjective judgment won't be involved when determining whether or not the shoulder belt slipped out of the clavicle. Furthermore, given that we don't know at all yet to what degree the seat belt's slipping out of the clavicle influences injury values such as chest deflection, we will need to continue studying its influence on injury values.

On an actual human body, the seat belt rarely slips out of the shoulder although it may be significantly twisted, because not only is the seat belt restrained by the notch formed by the clavicle and the coracoid process, but also the shoulder blade is movable in all directions along the ribs in such a way that the restraint point moves as well. On the other hand, there are limitations to evaluating the shoulder belt's slipping out with the AF05 dummy, because not only does it restraint the seat belt solely with the over-the-clavicle part, but also the clavicle part is not movable in all directions. Therefore, to achieve an accurate evaluation of the seat belt's slipping out of the clavicle in the future, it will be necessary to use a dummy simulating the shoulder blades and the clavicle, such as THOR dummy.

REFERENCES

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