ANCAP CHILD OCCUPANT PROTECTION ASSESSMENT – PERFORMANCE OF AUSTRALASIAN CHILD RESTRAINTS IN FULL SCALE CRASH TESTS

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ABSTRACT

From the start of 2018 ANCAP's testing and assessment protocols are substantially common with those of Euro NCAP. One key area of difference is assessment and rating of Child Occupant Protection (COP). While alignment of protocols is maintained where possible, differences in products and in vehicle installations require a unique assessment.

The differences arise from a mandatory product standard regulating Child Restraint Systems (CRS) in the Australasian market (AS/NZS 1754). The requirements of the standard mean that all booster seats sold in Australia are high back boosters, while prohibiting of the use of ISOFIX attachments for booster seats. Australian law also mandates use of booster seats by age (up to 7 years).

The 2018 protocols see the first opportunity for assessment of the performance of Australasian booster seats in full scale frontal and side impact crash testing. Typical vehicle accelerations recorded in ANCAP frontal offset tests are above those specified by existing regulatory or consumer CRS testing, and some parties expressed concerns regarding performance of Australasian CRS in comparison with European specification restraints, in particular those CRS recommended by vehicle manufacturers and used in Euro NCAP dynamic COP testing.

The paper provides an overview of early results, considerations for vehicle manufacturers and areas for future consideration in relation to child booster seats in the context of consumer ratings.

INTRODUCTION

From the start of 2018, ANCAP's testing and assessment protocols are substantially common with those of Euro NCAP. However, one key area of difference is assessment and rating of Child Occupant Protection (COP).

The regulatory and usage environment for child occupants in Australia is significantly different to that of Europe, and while alignment of protocols is maintained where possible, differences in products and in vehicle installations are such that a unique assessment is required.

In particular, the differences in product and vehicle installations arise due to unique requirements contained in a mandatory product standard governing the design and performance of child restraints sold on the Australian market (AS/NZS 1754 [1]). Of most relevance are performance requirements within this standard that effectively ensure that all booster seats sold in Australia are high back boosters, while prohibiting of the use of ISOFIX attachments for booster seats. Australian law also mandates use of booster seats by age for occupants of up to 7 years, although best practice guidelines recommend use based on the match between the child's size and rear seat and seat belt geometry.

The 2018 protocols see the first opportunity for assessment of the performance of Australian booster seats in full scale frontal and side impact crash testing. Typical vehicle accelerations recorded in ANCAP frontal offset tests are above those specified by existing regulatory or consumer CRS testing, and some parties expressed concerns regarding performance of Australian CRS in comparison with equivalent testing using European specification restraints.

ANCAP's requirements for Child Occupant Protection from the start of 2018 are contained in two protocols:

- ANCAP ASSESSMENT PROTOCOL - Child Occupant Protection [2]; and
- ANCAP TEST PROTOCOL - Child Occupant Protection [3].

While child restraints and instrumented dummies have been included in ANCAP frontal offset and side impact tests for many years, the 2018 protocols are the first occasion where protection of child occupants forms part of the assessment of the vehicle.

In addition, the 2018 protocols assess children of a different age range to those used in previous ANCAP testing, with 1.5 year old and 3 year old occupants in CRS with integrated harness being replaced with 6 year old and 10 year old occupants in (generally) high-back booster seats.

The 2018 protocols therefore present a new challenge to vehicle manufacturers, particularly for those with vehicle types that have not previously been subject to Euro NCAP assessment. During the lead-up to implementation of the new protocols, ANCAP received representations from a number of vehicle manufacturers suggesting that in-house testing had shown difficulty achieving comparable performance in vehicles fitted with Australian CRS when compared with vehicles of the same specification tested using European specification restraints.

With a range of vehicles of different types having now been tested to the new ANCAP protocols, there is an opportunity to examine performance against the COP dynamic testing and assessment protocols, and to further examine similarities and differences between the performance of the different restraint types.

In this paper, restraints that have been manufactured and certified to the Australian / New Zealand Standard (AS/NZS 1754) and supplied in Australia are referred to as AU. Restraints supplied and used in Europe (meeting UN Regulation 129) are referred to as EU.

BACKGROUND

Child Restraint Requirements in Australia

In Australia, the road rules require vehicle drivers to secure children aged up to 7 years old in an approved child restraint system. For infants up to 6 months of age this must be a rearward-facing CRS with an in-built harness. For children who are 6 months or older, but less than 4 years, this must either be a rearward-facing or a forward-facing CRS with an in-built harness. For children who are 4 years or older, but less than 7 years, this must be a forward-facing CRS with an in-built harness or a booster seat. Children who are 7 years or older, but less than 16 years, must be secured using a child restraint (CRS with in-built harness or booster seat) or by a seatbelt only.

Australian road rules also prohibit children under 4 years old from travelling in the front row of a vehicle with 2 or more rows of seats. Further, children who are 4 years or older but less than 7 years, are prohibited from travelling in the front row of a vehicle with 2 or more rows of seats, unless all seats in the rear rows are occupied by children who are also less than 7 years old. These requirements are to minimise the risks associated with young children travelling in the front seat, including in particular (but not limited to) the risk associated with the installation of a rearward-facing child restraint in a seating position with an active airbag.

Australian /New Zealand Standard AS/NZS 1754 is a mandatory product safety standard and has historically included a number of significant differences in comparison to European product standards. The standard requires that all dedicated child restraint systems, including booster seats, prevent contact between the test dummy's head and a static side door structure in a simulated 90 degree impact. This requirement effectively removes backless booster seats (other than those sold as part of the vehicle i.e. integrated boosters) from the Australian market.

AS/NZS 1754 includes requirements for materials (e.g. webbing, coated metal parts, plastics), general design and construction, dynamic performance, labelling, instructions, marking and packaging.

To meet AS/NZS 1754 a child restraint must satisfy the requirements for at least one designated restraint type. Convertible restraints must meet the requirements set out for the applicable combination of types (e.g. A2/B, A4/B, B/E, B/F etc.). Table 1 summarises each designated restraint type defined by this standard (excluding the Type C harness and the Type H converter). Shoulder height markers are required on all CRS (other than type C and H), providing guidance on when a child should transition to the next designated type, and are prescribed in such a way as to encourage transitions to be as late as possible.

Currently there are two types of booster specified in AS/NZS 1754; Type E boosters which are designated as suitable for use by children approximately 4 years to 8 years, and Type F boosters designated as being suitable for children aged approximately 4 to 10 years. All Type E and F boosters available in Australia are high back boosters.

AS/NSZ 1754 also designates an alternative form of restraint for children aged between 4 and 8 years. This is known as a Type G restraint, which is a forward-facing child seat designed to accommodate a larger child than the traditional Type B forward facing seat. The Type G seat incorporates an integral harness, and is anchored to the vehicle by the three point belt and a top tether strap.

Table 1.
Designated restraint types under AS/NZS 1754

Type Designation	**Description**	**Seated Shoulder Height**	**Approximate Age Range**
A1	Rearward-facing child restraint with in-built harness	Birth up to 290--320 mm	Birth to 6 months
A2	Rearward-facing child restraint with in-built harness	Birth up to 320--350 mm	Birth to 12 months
A3	Side-facing child restraint with in-built harness or other restraint means	Birth up to 290--320 mm	Birth to 6 months
A4	Rearward-facing child restraint with in-built harness	Birth up to 360--390 mm	Birth to 30 months
B	Forward-facing child restraint with in-built harness	From 290 mm up to 405--435 mm	6 months to 4 years
D	Rearward-facing child restraint with in-built harness	From 290 mm up to 405--435 mm	6 months to 4 years
E	Booster seat (child <128cm)	From 385 mm up to at least 475 mm	4 years to 8 years
F	Booster seat (child <138cm)	From 385 mm up to at least 530 mm	4 years to 10 years
G	Forward-facing child restraint with in-built harness	From 290 mm up to 490-510 mm	6 months to 8 years

Generally, AS/NZS 1754 requires child restraints to accommodate specified dummies representative of the smallest child (in summer weight clothing) and the largest child (in winter weight clothing) that the restraint type designation is intended to cover. This is to ensure that the large majority of children will fit properly within restraints of a given designated type, for at least the minimum period required by the road rules.

All restraint types except for booster seats and converters must include provision for attachment to the vehicle using a seatbelt in combination with a top tether. Booster seats greater than 2 kg in mass must also be fitted with a top tether. Rigid ISOFIX connectors or flexible lower anchorage straps/connectors are optional for restraints of Type A, B and D; and are prohibited for all other restraint types. Table 2 summarises the anchoring and attachment system requirements for each designated restraint type.

Finally, while AS/NZS 1754 does include some size requirements, in particular for Type F restraints, it does not include any reference to the European i-Size systems.

Table 2.
AS/NZS CRS Anchoring and Attachment Requirements

Type Designation	Anchoring and Attachment System				
	Anti-rotation Device		Seatbelt Anchorage	ISOfix Connector (Lower)	
	Top Tether	Foot prop (Support Leg)		Rigid	Flexible
A1, A2, A3, A4	✓	✗	✓	✓	✓
B	✓	✗	✓	✓	✓
D	✓	✗	✓	✓	✓
E, F	✓ CRS > 2kg	✗	✓	✗	✗
G	✓	✗	✓	✗	✗

✓ Mandatory ✓ Optional ✗ Prohibited

The dynamic tests required by AS/NZS 1754 include frontal impact, side impact with door, side impact without door, rear impact and inverted tests. For the frontal impact tests, the velocity change must be at least 49 km/h with a negative acceleration of between 24g and 34g for at least 20ms. For the side and rear impact tests, the velocity change must be at least 32 km/h with an acceleration of between 14g and 20g for at least 20ms.

The CRS must meet a range of general structural integrity related requirements for each prescribed test, including retention of the dummy in the restraint on the test rig. For the frontal impact tests, there are also maximum head acceleration limits for Type A and D restraints, head excursion limits for Type A, B, D and G restraints and requirements to limit both movement of the sash belt from the shoulder and submarining for Type E and F booster seats. For the side impact tests there are requirements to avoid head contact with the side door, while in the rear impact tests there are head excursion limits for Type A and D restraints.

Child Restraint Requirements in Europe

In Europe, children under 135 cm in height must, when travelling in light vehicles, be restrained in a United Nations (UN) Regulation No. 44 (R44) or a UN Regulation No. 129 (R129) approved child restraint, which is appropriate for their size and weight. Rearward-facing child restraints are permitted to be used in the front passenger seat, provided the airbag is deactivated. There is no restriction on the use of forward-facing child restraints or booster seats in the front seat.

All child restraints sold in Europe must be approved to either UN R44 or UN R129. Child restraints manufactured and approved to UN R44 are classified into five groups, based on child mass, and the child mass group (i.e. mass range) is indicated on the approval label affixed to the restraint. Child restraints manufactured and approved to UN R129 are classified according to the child height range for which the restraint is suitable, which is also indicated on the approval label affixed to the restraint. Further, maximum child mass is also included on the UN R129 approval label for CRS types with an integrated restraint system.

Under UN R129, child restraints are categorised as either i-Size restraints or specific vehicle restraints. i-Size restraints must meet a range of geometrical requirements to ensure they properly fit i-Size seating positions in vehicles. The requirements for i-Size seating positions are set out in UN Regulation No. 14. Specific vehicle restraints are approved for a specific vehicle type (i.e. model).

The dynamic tests required by UN R129 include frontal impact, side impact (with intruding door) and rear impact. For the frontal and rear impact tests, the requirements include general structural integrity related provisions for the CRS, dummy injury assessment criteria limits and head excursion limits.

In the lateral (side) impact tests, there are requirements for general structural integrity (of the CRS), dummy injury assessment criteria and head containment.

Differences between ANCAP and Euro NCAP

While ANCAP's COP testing and assessment protocols are closely aligned with those of Euro NCAP, there are a number of differences that reflect the nature of CRS available in Australasia, and the way in which they are used. The majority of the changes relate to the CRS Installation and Vehicle Based Assessment sections of the protocol and will not be discussed in this paper. The key differences that relate to the performance in the Dynamic Assessment sections are:

	Euro NCAP	ANCAP
CRS Type	Q6 seated in Booster Seat (High back). Q10 seated on Booster Cushion (no back)	Q6 - An "appropriate" forward facing CRS for a 6 year old child. This may be a Type E or Type F booster seat (with back and sides), or a Type G CRS with integrated harness. Q10 – a Type E or Type F forward facing booster seat. (If selected by the OEM).
CRS Selection	CRS as Recommended by OEM. If no recommendation is made, CRS is selected from "Top Pick List"	CRS may be selected by the OEM (no requirement for 'Recommendation') If no selection is made by the OEM, CRS is from ANCAP CRS list for Q6 and Q10 is placed on the vehicle seat (no CRS).
CRS Head Restraint		CRS head restraint is positioned as specified by vehicle manufacturer. Where no specification is made, CRS manufacturer installation directions are followed.
Fitting the CRS	ISOFIX permitted.	Type E and Type F CRS are installed using the adult belt and top tether. AS/NZS 1754 prohibits the use of ISOFIX attachments on booster seats.
Integrated CRS	Integrated CRS will be used even if they are optional equipment.	Where the integrated CRS is optional equipment, ANCAP will determine whether the optional CRS are to be fitted.

Dummy specifications, test set up (including seating locations), and performance criteria are common between the ANCAP and Euro NCAP COP testing and assessment protocols. Where integrated booster cushions are fitted to the test vehicle and suitable for either the Q6 or Q10 dummy the booster seat they are used for these occupants under both ANCAP and Euro NCAP, however the application for optional integrated seats is different between the two programs (to date ANCAP has not tested any vehicle with an integrated booster seat/cushion).

ANCAP CRS Selection List

As with Euro NCAP, ANCAP's COP protocols include an assessment of installation of a range of child restraints in each vehicle that is rated. However, a key difference is that ANCAP's "CRS Selection List" is intended as a selection of typical, readily available child restraints covering each of the applicable CRS types in the Australian / New Zealand standard, with no relative assessment of the performance of each CRS against other available products (and therefore is not a 'Top Pick' list). The CRSs were chosen, where applicable, to include ISOFIX attachments in addition to the mandatory belt installation, allowing assessment of installation in both modes.

There is no requirement that the CRS selected by vehicle manufacturers for the dynamic tests be chosen from the CRS Selection List, and manufacturers can and do select from the full range of CRSs of the specified types.

COP scoring matrix and considerations

The scoring distribution under COP for ANCAP is the same as the Euro NCAP COP protocol, though ANCAP awards default points for a subset of the static CRS installations. ANCAP also rewards the provision of ISOFIX seating positions, rather than i-Size, which is not applicable under the Australian / New Zealand standard for CRS.

Table 3.
COP Scoring for ANCAP and Euro NCAP

	Euro NCAP (49)	ANCAP (49)
Dynamic Assessment	(24)	(24)
Frontal Impact	16	16
Side Impact	8	8
Vehicle Based Assessments	(13)	(13)
Gabarit Installation on all Passenger Seats	2	2
i-Size and TopTether Marking	3	-
ISOFix Availability	-	3
Two or more ISO/R3 Positions	1	1
Passenger Airbag Warning Marking and Disabling	4	4 (Default 2)
Integrated CRS	3	3
Installation of Child Restraints	(12)	(12)
Universal seats	4	4
Belted with top tether seats		
ISOFIX seats	2	2
i-Size seats	4	Default 4
Recommended seats	2	Default 2

As is the case with Euro NCAP, most vehicles score 8 or fewer points out of 13 for the Vehicle Based Assessment. As a result, the Dynamic Assessment becomes critical for the COP score and ultimate star rating for a vehicle. The minimum score for a 5 star rating in 2018 is 39.2 points, and therefore a vehicle with a Dynamic score lower than approximately 20 is unlikely to be eligible for the highest star rating.

Chest Injury Metrics

At the start of 2018 a change to the chest injury metric for the Q6 dummy has been applied. Under Euro NCAP protocols up to the end of 2017 the chest injury score was calculated from chest (thoracic spine) acceleration, with the higher performance threshold being set at 41g. From 2018 (version 7.2 of the protocol) and for all ANCAP COP assessments, the chest score is calculated from chest deflection, with a higher performance threshold of 30mm. In order to enable comparison of 2017 and 2018 results, both metrics are recorded and presented in this paper. Chest deflection is also presented for the Q10 dummy, which is fitted with upper and lower deflection sensors (IR-TRACCs) – no performance criterion has been specified for the Q10. For normalisation an arbitrary value of 30mm has been applied in this analysis.

Table 4.
Frontal impact criteria, limits and available points per body region for Q6, Q10

	CRITERION	**Performance limits**			**Available points**
		Higher	**Lower**	**Capping**	
Head Score	HIC15 (with hard contact)	500	700	800	4 points
	Resultant 3ms acceleration	60g	80g	80g	
	Head excursion modifier				
	Q6	450mm	550mm	NA	
	Q10		550mm	NA	
Upper Neck	Tension Fz	1.7kN	2.62kN	NA (monitoring)	2 points
	Extension My (with head to interior contact)				
	Q6	NA	36Nm	NA	
	Q10	NA	49Nm	NA	
Chest (T4)	Resultant 3ms acceleration*				
	Q6	41g**	55g**	NA	NA
	Q10	41g	55g	55g	2 points
	Deflection				
	Q6	30mm (monitoring)	42mm (monitoring)	NA	2 points
	Q10			NA	NA
TOTAL					**8 points/dummy**

** 2017 limit values

METHODS

The analysis draws on three separate sets of data from full scale crash tests. All results are from frontal crash tests into an Offset Deformable Barrier at 64 km/h in accordance with the "ANCAP Test Protocol – Frontal Impact Offset Deformable Barrier" (v7.1.2) [4]. The test requirements of this protocol are the same as in the Euro NCAP "Offset Deformable Barrier Frontal Impact Test Protocol" (v7.1.2).

AU/EU Comparison Tests

Data were available for two vehicle models that were tested separately by Euro NCAP and ANCAP, allowing comparisons of the COP performance between AU and EU CRS. In some cases, the ANCAP tests formed part of the laboratory commissioning process for the 2018 protocols and were not part of official rating programs. Data were available for two vehicle models, one a small SUV and one a medium SUV. The performance of both models for adult occupant protection is good, and both models carried 5 star ratings under ANCAP and Euro NCAP. It is worth noting, however, that vehicles tested in Australia were right-hand-drive, while the vehicles tested by Euro NCAP were left-hand-drive. This has some effect on the vehicle crash pulse measured at the B-Pillar.

ANCAP Ratings

Complete COP data are available for five vehicle models that have been tested and rated by ANCAP in 2018. These represent a cross section of vehicle types including small and medium family cars, medium and large SUVs. None of the rated vehicle models had been previously tested by ANCAP or Euro NCAP. The CRS used in each case were selected by the vehicle manufacturer. The CRS selections included Type E and Type F booster seats, with both types being applied for Q6 and Q10 occupants.

The Q6 and Q10 dummies were fitted with all instrumentation specified in the ANCAP (and Euro NCAP) COP test protocols.

Comparison Test with Q10 on Adult Seat

An ODB test was conducted on one further vehicle model as part of a separate ANCAP program. The opportunity was taken to place a Q10 dummy on the (passenger side) rear seat, in order to assess performance with no booster seat (or booster cushion). A Euro NCAP test result was available for a variant of the same model for comparison, with the Q10 in the EU vehicle being installed on a booster cushion and restrained by the adult belt. In this case there were some differences in the drivetrain between the EU and AU vehicle, which in combination with a change from left-hand-drive to right-hand-drive resulted in a more severe crash pulse for the AU vehicle on the struck side, however the B-Pillar acceleration on the non-struck side (more relevant for the Q10) was not recorded in the Euro NCAP test and therefore is not presented in this study.

RESULTS

General

There was no hard contact observed between the child dummies and the CRS or vehicle interior in any of the tests. HIC_{15} and Neck Extension Moment are therefore not considered for point-score or rating, but are presented for information. With the changes in chest injury criteria, both deflection and acceleration values are reported. The metrics that are not applicable under 2018 protocols are shaded in charts below for clarity.

Injury metrics presented are normalised against the "Higher Performance" threshold of ANCAP and Euro NCAP protocols. As previously noted, an arbitrary value of 30mm is applied for normalisation of Q10 chest deflections. For the Q10, the values displayed are from the Upper IR-TRACC, which in all cases recorded greater deflection than the lower sensor.

Comparison of results – Australian vs European CRS

Comparison of accelerations at the driver's side B-Pillar shows comparable load cases for the EU and AU CRS, though there is some variation in the peak recorded acceleration. As an additional indicator, the *Occupant Load Criterion* (OLC) [5][6] was calculated using the driver's side B-pillar acceleration for each vehicle. Calculated OLC values are listed in Table 5. For the medium SUV the calculated OLCs were very close. For the small SUV, the EU vehicle showed a slightly higher OLC.

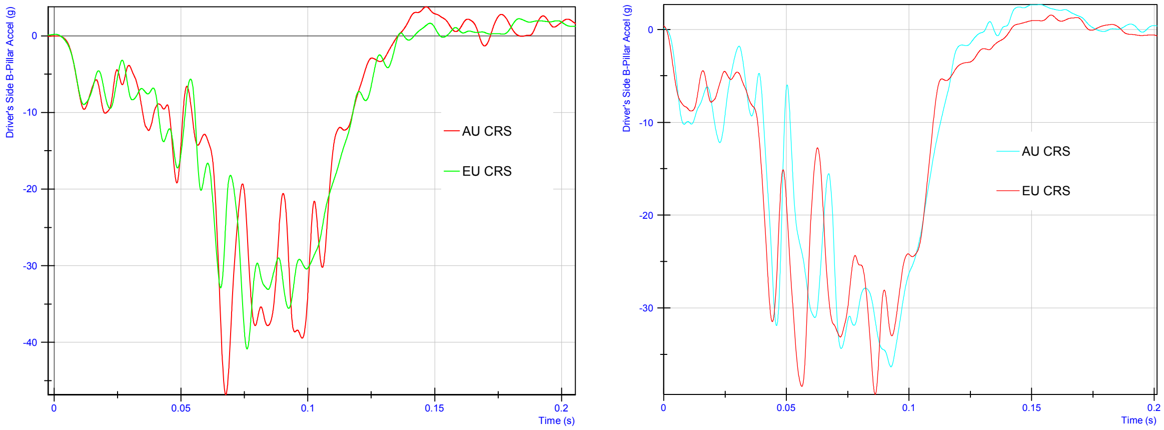

Figure 1 - B-Pillar Acceleration Comparison - Medium SUV (left) and Small SUV (right).

Table 5.
Occupant Load Criterion Comparison - AU and EU CRS

Occupant Load Criterion	Medium SUV	Small SUV
AU (ANCAP)	25.83	26.33
EU (Euro NCAP)	25.38	28.88

Figure 2 shows the injury metrics from the comparison tests. In both cases there is good correlation between the injury metrics of the ANCAP and Euro NCAP test vehicles.

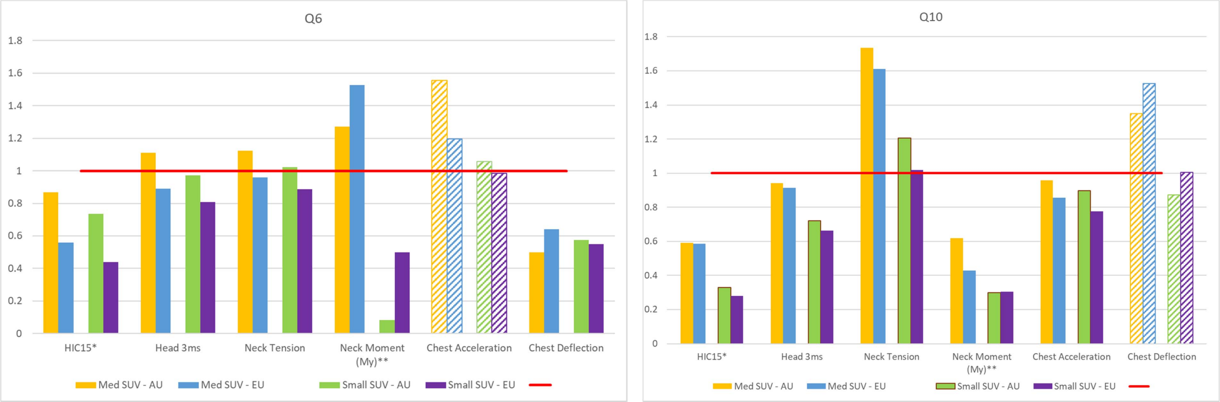

Figure 2 - Comparison of Injury Metrics for Q6 and Q10 with EU and AU CRS.

Results from 2018 ANCAP Ratings Testing

In tests conducted to date, there have been consistently good overall results shown in ANCAP testing for dynamic child occupant protection. While in some cases there were injury metrics that exceeded the higher performance thresholds, there was only one result exceeding the lower performance threshold. The results are shown in Figure 3.

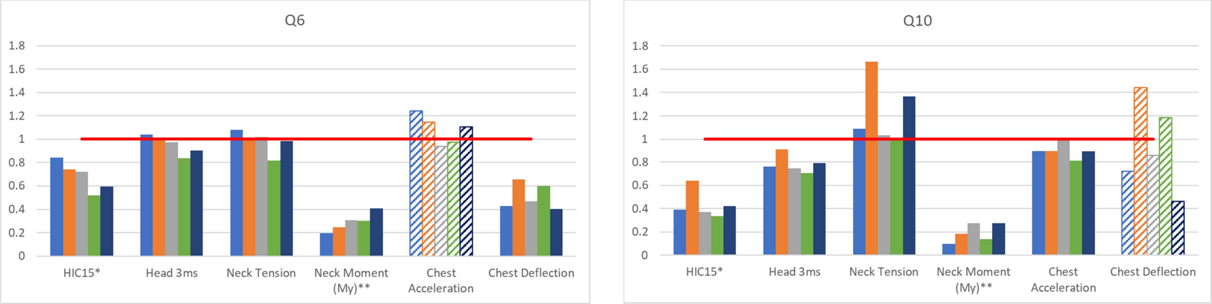

Figure 3 - Normalised results from ANCAP ratings

All vehicles rated during 2018 achieved the COP points score threshold necessary for a 5 star rating. The COP point scores for the five vehicles are shown in Figure 4, identifying the contributions of each of the areas of assessment.

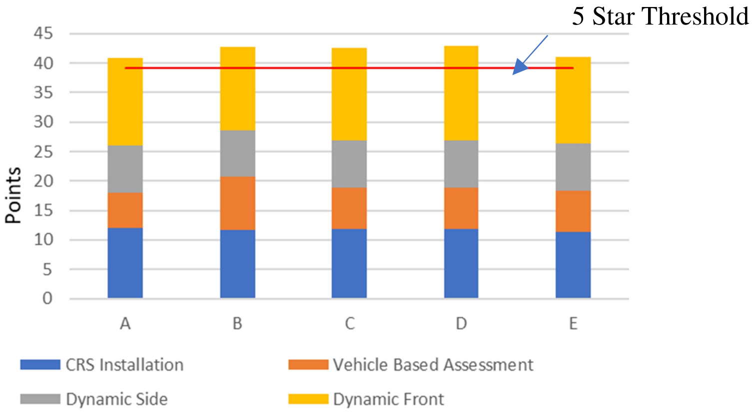

Figure 4 - Comparison of COP point scores for 2018 ANCAP ratings

Results from Comparison Test with Q10 on Adult Seat

Injury metrics for the Q10 were very similar between the two tests (Figure 5) however, where the Q10 was seated on the adult seat without any booster cushion, submarining of the dummy was observed, with the lap belt slipping upwards off the dummy's pelvis and into the abdomen (Figure 6). Submarining was not observed in the test with the Q10 on the booster cushion. Under the ANCAP assessment protocol, a capping modifier is applied to the score where submarining occurs and zero points are scored for that occupant.

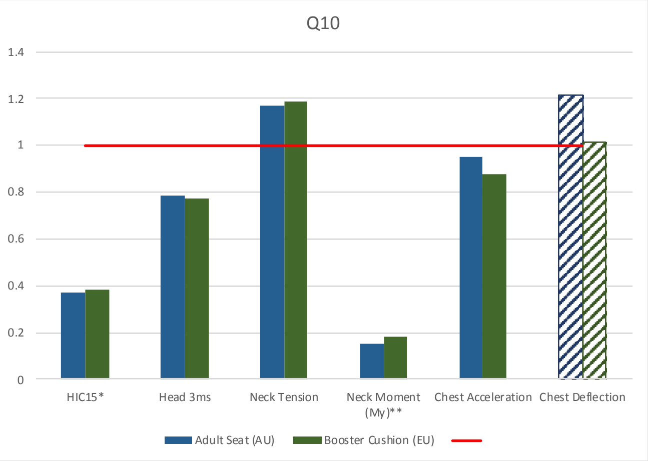

Figure 5 - Comparison of Q10 Injury Metrics on Adult Seat with Booster Cushion.

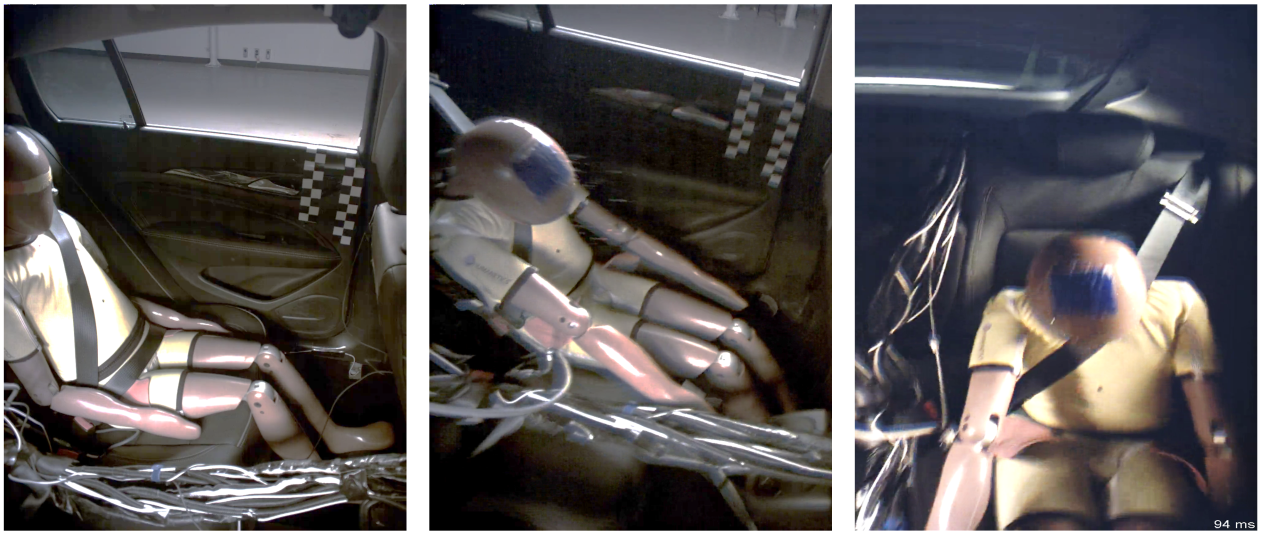

Figure 6 - Submarining of the Q10 on the Adult Seat - Pre-impact (Left) and During the impact.

DISCUSSION

Seat-belt Path

One factor that may result in variations in test performance of AU child restraints appears to be the path of the seatbelt through the CRS belt guide. All of the booster seats have a belt guide that sets the position of the belt over the dummy's shoulder, but that can also introduce friction to the belt. This seems to be most significant where there is a large deviation in belt path due to the belt guide, resulting in a 'z-shaped' belt path (see examples in Figure 7). It appears possible, though not investigated in depth at this time, that friction from the belt guide may inhibit effectiveness of the pre-tensioner, and result in sub-optimal injury metrics. Location of the belt guide also affects the position of the belt across the dummy chest, which may influence chest deflection results.

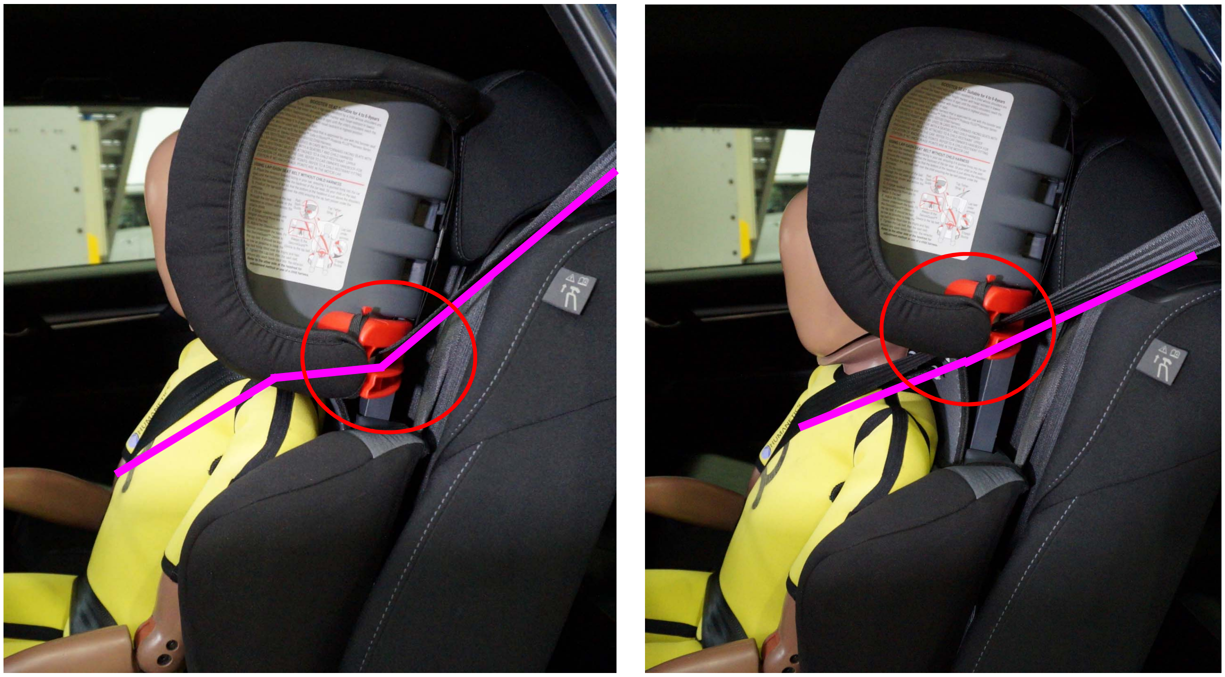

Figure 7 - Examples of Seat Belt Path with CRS in lowest (left) and upper-mid (right) positions

The ANCAP COP testing protocol allows the vehicle manufacturer to specify the position of the head restraint of the selected CRS, which in most cases will result in a CRS head restraint that is higher than the position specified by the CRS manufacturer (which is generally the lowest position for which the shoulder height marker is above the shoulder) and results in a straighter belt path through the CRS belt guide.

The general behaviour of belt guides in high severity crash tests of vehicles with advanced seat belts is an area that warrants some further research.

Chest deflection of Q10 – Type F CRS

For both the Q6 and Q10 child dummies, the ANCAP protocol allows the manufacturer to select either Type E or Type F booster seats – and both types have been applied for both occupant sizes in the tests that have been conducted.

As noted in a study by Adalian and Bendjellal [7], a lower chest deflection was recorded with an AU booster than the EU booster for the same selection of vehicles. It is noted that the AU Type F booster seat, as used in that analysis, has no armrest or belt guide at the buckle. This is a consequence of width requirements for the Type F booster that are included in the Australian / New Zealand Standard.

In ANCAP tests with AU restraints the same trend was noted, with generally lower chest deflections recorded in Type F CRS than in tests using European specification booster seats or using AU Type E seats (noting that the sample size is small at this point).

With no lower belt guide, the belt takes a more rearward position at the hip, allowing the upper part of the belt to sit higher on the dummy thorax, which may influence the deflection measurement.

CONCLUSIONS

From the testing conducted to date the following conclusions have been drawn:

- Good dynamic performance can be achieved in the 64 km/h Offset Deformable Barrier crash test when using Australian / New Zealand Standard child restraints.
- It is realistic for current vehicles to consistently meet 5 star performance requirements under the COP Pillar of current ANCAP protocols.
- Child Occupant Protection performance can be expected to be similar when comparing tests of the same vehicle model using AU and EU child restraints.
- Neck tension was the most common exceedance of the ANCAP higher performance limits.
- Consideration of the CRS selected for dynamic testing, and specifying the applicable CRS head restraint position are likely to contribute to higher overall scores.

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ASSESSMENT OF NEW ACTIVE SAFETY SYSTEMS ADDRESSING URBAN INTERSECTION SCENARIOS INCLUDING VULNERABLE ROAD USERS

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ABSTRACT

Bicyclists and pedestrians belong to the most endangered groups in urban traffic. The EU-funded collaborative research project PROSPECT (‘PROactive Safety for PEdestrians and CyclisTs´) aims to significantly improve safety of those unprotected traffic participants by expanding the scope of scenarios covered by future active safety systems in passenger cars. Concepts for sensor control systems are built into three prototypes covering emergency interventions such as Autonomous Emergency Braking (AEB) as well as Autonomous Emergency Steering (AES). These systems tackle the well-known challenges of currently available systems including limited field-of-view by sensors, fuzzy path prediction, unreliable intent reaction times and slow reaction times. These highly innovative functions call for extensive validation methodologies based on already established consumer testing procedures. Since these functions are developed towards the prevention of intersection accidents in urban areas, a key aspect of the advanced testing methodology is the valid approximation of naturalistic trajectories using driving robots. Eventually, several simulator studies complemented a user acceptance and benefit analysis to evaluate the expected overall impact of the PROSPECT systems.

The results achieved within the PROSPECT project are highly relevant for upcoming test protocols regarding the most critical situations with Vulnerable Road Users (VRU). With introducing the new methods in Euro NCAP (European New Car Assessment Programme) a significant increase in road safety is expected.

INTRODUCTION

Accidents involving bicyclists and pedestrians remain a significant issue for road safety, accounting for more than 25% of road fatalities in the European Union [1]. This value stresses the importance to take measures aimed to reduce the number of occurring fatalities with vulnerable road users (VRU) significantly. The corresponding intention of the European Union planning to move close to zero fatalities in road transport by 2050 is already stated in the white paper (Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport systems), which was published in 2011[2].

To meet these ambitious goals, Advanced Driver Assistance Systems (ADAS) are a promising option to focus on active safety systems addressing VRU safety. Autonomous Emergency Braking systems (AEB) are already established in state-of-the-art consumer testing [3]. Consumer test organizations such as Euro NCAP (European New Car Assessment Programme) have a high impact on vehicle safety by introducing transparent safety requirements and accompanying test procedures. Consumer testing is considered to be an important part of vehicle safety, therefore PROSPECT (‘PROactive Safety for PEdestrians and CyclisTs´) will supply test procedure proposals to Euro NCAP (the dominant vehicle consumer testing organization in the EU-28) starting in 2020.

PROSPECT is a collaborative research project funded by the European Commission. The project pursues an integrated approach comprising in-depth and multiple European accidents studies involving VRUs, combined with results from urban naturalistic observation. Real intersections throughout Europe were monitored to understand critical situations that occur between vehicles and VRUs. The gained knowledge from these observations is used to identify crucial factors leading to conflict situations and to better anticipate accidents. As the output, the most relevant accident scenarios are identified for pedestrians and cyclists focusing on urban environments, where the majority of accidents involving VRU occur. Further on, generic use cases were derived as basis for the development of test scenarios for the ADAS systems. Proposed test cases derived from the accident data as well provide a description of how to reproduce a specific use case on closed test tracks.

The accident analysis represents a key input for the system specifications for development of the three project prototype vehicles. These demo-vehicles are extensively tested in more realistic scenarios. PROSPECTs broad testing methodology goes beyond what is currently used in consumer testing, such as turning in intersection scenarios based on naturalistic driving observations in real traffic throughout Europe. The concept for more realistic testing includes intersection markings which allow the efficient testing of all test cases, mobile and light obstruction elements and realistic surroundings like traffic signs or lights. Eventually, the testing results from the prototype evaluation as well as several simulator studies build the basis for an over benefit analysis assessing the socio-economic benefit of the developed functions. The PROSPECT methodical approach is presented below in *Figure 1*.

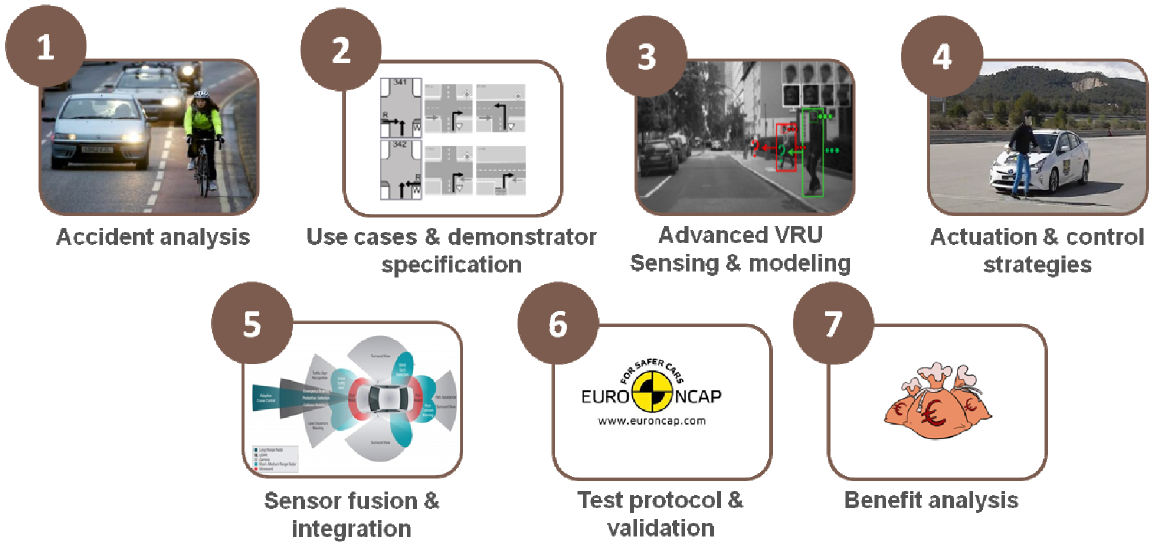


Figure 1: PROSPECT methodology

The findings within PROSPECT contribute not only to the state-of-the-art knowledge of VRU-vehicle behavior, but to technical innovations, i.e. assessment methodologies and tools for testing of next generation VRU active safety systems, as well. In terms of the estimated impact, the introduction of a new level of safety systems in the market will enhance VRU road safety in the 2020-2025 timeframe, contributing to the ‘vision zero’ objective of no fatalities or serious injuries in road traffic set out in the Transport White paper. Test methodologies and tools are considered for 2022-2024 Euro NCAP road-maps.

This paper will focus on the test protocol and prototype evaluation that was conducted within the PROSPECT project. Initially, the derivation of test cases based on the accidentology is explained followed test protocol development. Eventually, the assessment of the prototype is exemplarily explained. In the discussion section, the findings and limitations are summarized and an outlook is given.

From Accident Analysis over use cases to test cases

The first stage of the project included macro statistical and in-depth accident studies targeting VRU accidents in urban traffic. The studies were performed in Europe focused specifically on pedestrians and cyclists. An overview and an in-depth understanding of the characteristics of road traffic crashes involving vehicles and VRUs (i.e. pedestrians, cyclists, riders of motorcycles, e-bikes and scooters) was provided for different European countries. Early investigations have shown that the crashes between passenger cars and pedestrians or cyclists are the most relevant in Europe. *Figure 2* shows a summary of the most relevant accident scenarios related to car-to-cyclist crashes that were extracted from this study.

The in-depth understanding of the crashes includes the identification of the most relevant road traffic accident scenarios and levels of injury severity sustained, as well as the transport modes that represent a higher risk for VRUs. Besides extensive literature studies, comprehensive data analyses have been performed featuring information from recent years. From the most relevant accident scenarios, detailed car-to-cyclist crash analyses have been performed focusing on the causation of crashes: car-to-cyclist accidents have been analyzed from the car driver’s point of view. With this approach deeper insight can be gained about situations faced by the drivers especially why they sometimes failed to manage these crash situations [4].

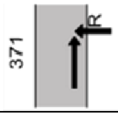
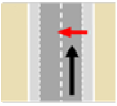
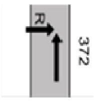
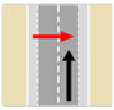
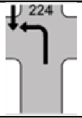
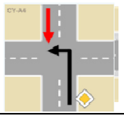
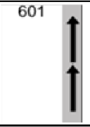
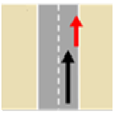
Accident type	UTYP Pictogram	PROSPECT pictogram (basic version)
(I) Car straight on, cyclist from near-side		
(II) Car straight on, cyclist from far-side		
(III) Car turns		
(IV) Car and cyclist in longitudinal traffic		
(V) Others		

Figure 2: Overview of most relevant accident scenarios between passenger cars and bicyclists.

The accident scenarios obtained from the studies describe the type of road users involved in the accident, their motions (e.g., the motion of the cyclist or pedestrian relative to the vehicle) expressed as accident types and further contextual factors, like the course of the road, light conditions, weather condition and view obstruction. More information is available on the project deliverable “Accident analysis, Naturalistic Driving studies and Project implications” [5].

The most relevant accident scenarios have been clustered in use case or target scenarios addressed by the project. These use cases contain less detailed information and are used to derive the sensor specifications of the prototypes including information, such as stereo vision base line, image resolutions, microwave radar sensitivity/accuracy or the necessary field of view of the corresponding sensor. Additionally, issues related to sensor processing required by the chosen scenarios including VRU detection areas, correct vs. false recognition rates, localization accuracy and computational latencies had to be taken into account. Since the safety systems developed within PROSPECT are relying on video and radar based technology constantly surveying the surroundings of the vehicle by an extended field of view, more complex scenarios can be addressed than currently state-of-the-art systems are capable of. Specific information on the configured and evaluated prototypes is available in the related PROSPECT deliverable [6].

The final goal was to define representative Test cases from available Use Cases, taking into account relevant parameters and representative values for the selected parameters based on accident potential and system analysis. Constraints taken into account are a limited and feasible number of test runs, durability (e.g. maximum impact speed) and the feasibility of the test tools (see *Figure 3*).

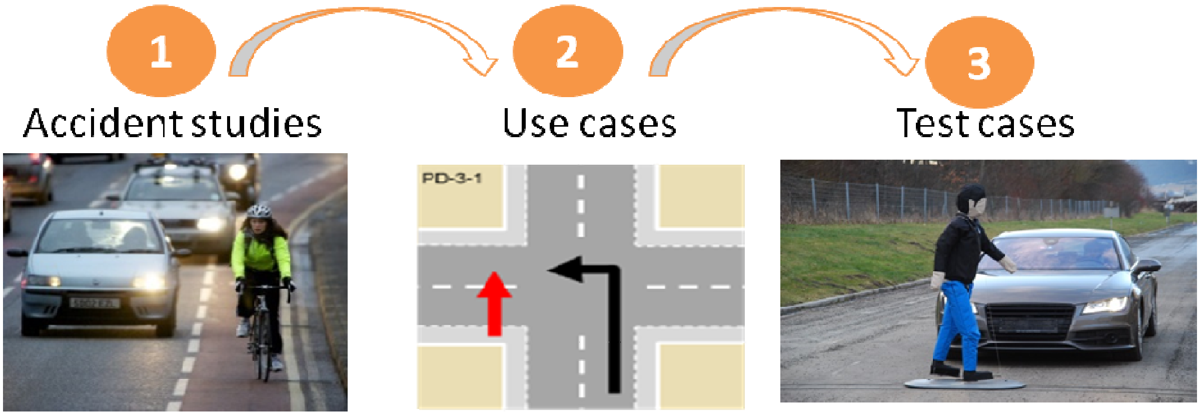


Figure 3: From accident analysis to test cases - scheme

TEST PROTOCOLS

For the benefit assessment of the prototype vehicle's functionality a testing methodology is required that goes beyond what has currently been used in European consumer testing (Euro NCAP). While under evaluation, the Vehicle Under Test (VUT) has to be equipped with driving robots, including a steering and pedal system as well as a DGPS measurement system, to keep each individual test repeatable and comparable between vehicles. This equipment ensures a reproducible path for the VUT with a lateral tolerance of less than 5 centimeters (see *Figure 4*, left). In PROSPECT the crash opponent is a VRU dummy on a self driving platform which is time-synchronized with the VUT. In *Figure 4* the test tools are displayed. In various accidents that had been analyzed for the use case definition, the VRU was significantly often hidden by obstructive element. Bringing a solid obstruction element into consumer testing, the test are becoming more and more advanced for the safety systems to fully avoid impacts (see *Figure 4*, left below).

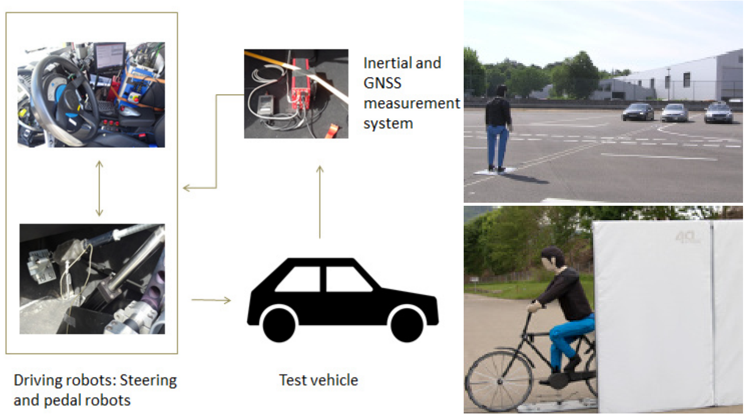


Figure 4: VUT testing equipment (left); Pedestrian and bicycle dummy with obstruction (right)

In the following the main two adaptations regarding the introduction of a basic intersection layout and the use of naturalistic trajectories reproduced by using driving robots are explained.

Intersection design

Intersections and the possibilities for different drivers to turn in these intersections are various. Defining a specific layout where all addressed scenarios could be tested is the initial step to limit the options for turning scenarios on the one hand and on the other hand, it already prepares the testing procedure for more advanced technologies that would be able to take the intersection boundaries into account for the decision on their behavior. The proposed intersection in PROSPECT (see *Figure 5*) is based on German recommendations for road construction for urban environmental intersections [7]. The intersection layout allows a cornering radius ranging from 8 – 15 meters. Aligning this with the information from the detailed accident analyses that measure the impact speeds in urban intersection accident scenario in a range from 10 to 25 kph will result in estimated lateral accelerations below 3 m/s².

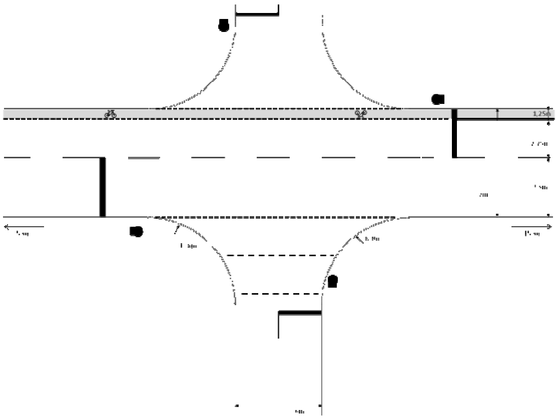


Figure 5: Intersection layout proposed by PROSPECT

The advantage of that simple intersection design is that depending on the future test cases at hand and the intention of the potential test, the suggested intersection layout can be easily adapted to a bigger size. PROSPECT proposed a small intersection as a start for future VRU test cases, but depending on increased driving speed and the desired trajectory it might be of interest to set up a medium to large intersection. In *Figure 6* the idea for designing custom intersections for oncoming scenarios is shown.

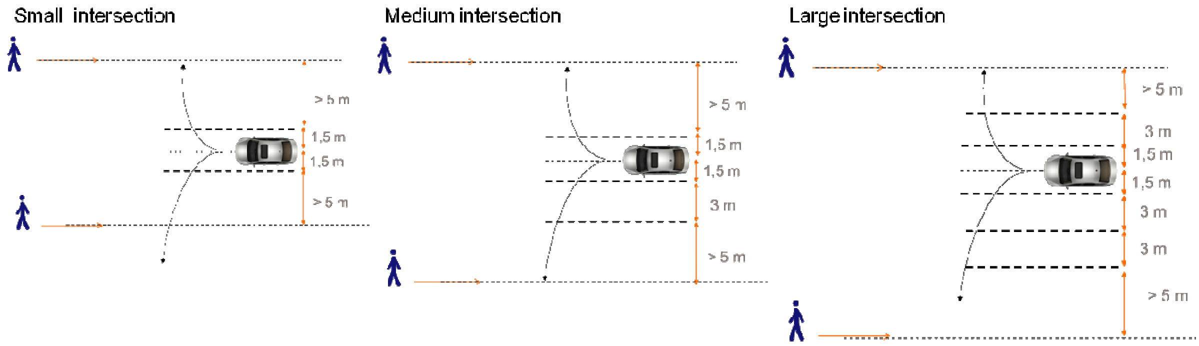


Figure 6: Different intersection sizes depending on the test design.

Trajectories

For the analysis of realistic driving behaviour, naturalistic driving studies (NDS) were conducted to observe the behaviour of different driver in different countries throughout Europe. Unfortunately, real intersection layouts highly vary regarding basic parameters such as lane width and the angle between the two crossing streets. Of course, strong variations can be found in other characteristics, especially regarding the environmental features. In urban areas buildings, parked cars or trees often block the free view over the approaching street arm. Additionally, surrounding traffic, for example oncoming cars, alters the chosen trajectory and speed profiles to a not negligible extent. As a result, the collected data shows a wide range of possibilities how to negotiate many variants of different intersections.

As mentioned above, consumer testing scenarios require a high repeatability ensuring a sufficient comparability of the results. Moreover, any additional test scenario is under strong boundaries regarding a reasonable time and money frame for the executing test laboratories. Therefore, the aim for generating feasible trajectories on closed test tracks is to simplify out of the whole range of possible real turning scenarios into one or a few signature trajectories representing the data found in the naturalistic driving studies and accident analyses as best as possible. As can be seen in *Figure 7*, restricting the intersection geometry stills leads to various possible trajectories.

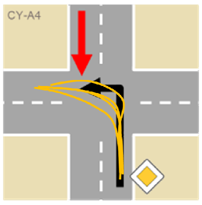


Figure 7: Possible trajectories for a given intersection layout depending on various factors, including obstructions, traffic, and driver condition.

Nevertheless, a detailed analysis of the available data shows that despite the differences in highest curvature, start and end position of the vehicle, the overall process of negotiation a turn is similar almost every time and can be split into three sections (see *Figure 8*) consisting of two clothoids and a constant radius.

- Section 1 Linear increase of the curvature, corresponding to curve entry
- Section 2 Constant radius cornering
- Section 3 Linear decrease of the curvature, corresponding to the curve exit

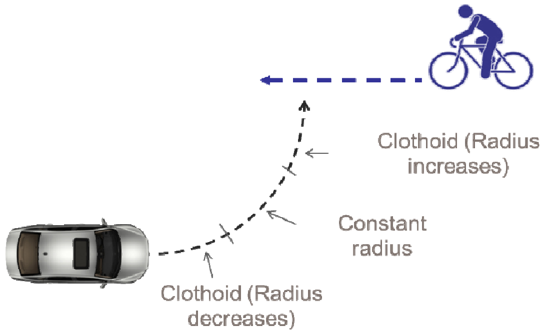


Figure 8: schematic description of the cornering sections

There is a tendency for the last section to be longer than the prior sections in the data from the naturalistic driving studies. This turned out to be of difficulty for the testing equipment on the test track. To be able to ensure tight tolerances over a wide variety of Vehicles under Test (VUT), the sections were split equally with a length distribution of 1/3 each. In *Figure 9* the derived trajectory based on the naturalistic driving data, accident analysis and testing experience is shown in *Figure 9* (solid line). The dashed lines represent selected trajectories from the naturalistic driving studies for one specific intersection close to the layout chosen in the project.

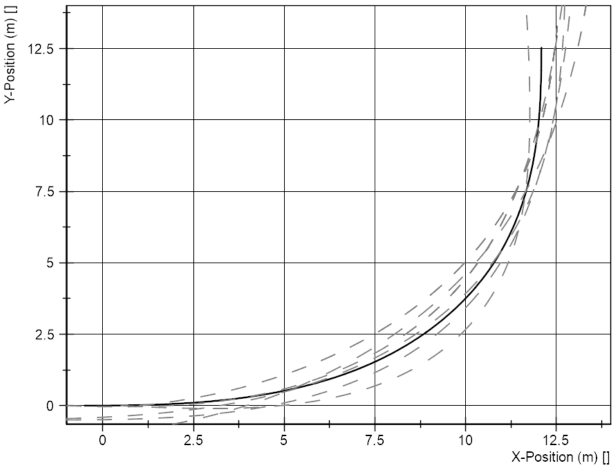


Figure 9: PROSPECT trajectory (solid) overlaid with selected naturalistic driving trajectories

The selected trajectory is a compromise between manifold possibilities provided by human driver behaviour and a repeatable and easy-to-use trajectory on the test track.

EVALUATION OF PROTOTYPES

The vehicle-based functional tests have been carried out in 2017 and 2018. Initially some of the PROSPECT use cases were reproduced in proving grounds with four production vehicles equipped with state-of-the-art active safety systems respecting VRU protection. These baseline systems are able to identify pedestrians and bicyclists and if necessary react in dangerous situations. With respect to current consumer test programmes these reference cars have achieved the highest qualification. These preliminary tests allowed obtaining the baseline performance of current AEB systems applied to VRU. The vehicles were treated anonymously when releasing the results, because only the average performance of market vehicles is of interest. Moreover, the reference testing helped to define the methodology and test procedures that were later used to evaluate the three prototype functions developed in the project.

Scenarios involving bicyclists are generally more challenging for the safety systems as they travel faster than pedestrians. Functions need to process and identify hazard situations as quick as possible to activate the automatic braking or steering application and avoid the crash. Therefore, only the longitudinal test case (bottom right in *Figure 10*) is additionally conducted with a pedestrian dummy. The velocity of the bicyclist is 15 km/h, for the pedestrian the velocity is set to 5 km/h. All scheduled test cases are displayed in *Figure 10*.

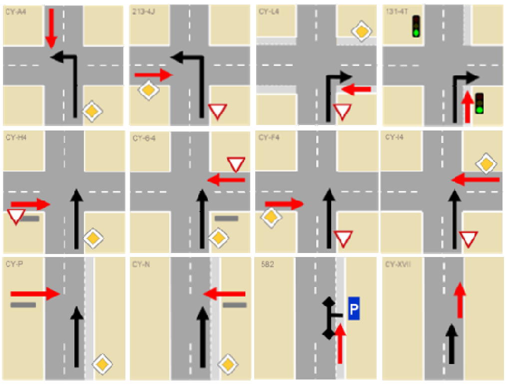


Figure 10: Assigned prototype test cases

The top row of the figure contains all intersection scenarios where a turning trajectory is required. In the middle row and the two left cases of the bottom row of the figure, crossing scenarios are shown. The second to last scenario describes a parking test case. The VUT is parked and the bicycle dummy is coming from the back. The test engineer opens the door when the dummy is close to the vehicle. The last scenario on the bottom right of the figure is the longitudinal test case. This scenario was conducted with more than one prototype and with different parameters regarding the placement of the VRU-dummy and the autonomous vehicle intervention. The basic setup of this scenario was conducted with 25% and 50% offset between VRU und VUT. For higher speeds ranging from 50 to 60 km/h, one prototype showed an ESP-induced emergency steering manoeuvre, while another prototype vehicle applied some torque on the steering wheel for the evasive manoeuvre. The dummy was placed to the very right side of the lane for this specific case.

The Euro NCAP ‘Test Protocol AEB-VRU systems’ [3] is the reference document mainly used to reproduce the crossing and longitudinal scenarios. The document provides the test tolerances for test velocities, lateral deviations and steering wheel velocities among others that are strictly followed by test laboratories for the evaluation of AEB VRU systems. Both stationary and turning scenarios are not yet part of Euro NCAP test protocols and therefore a PROSPECT test protocol had to be developed. The challenges regarding the derivation of naturalistic trajectories were described above.

Results

In the following exemplary final test procedures and test results are shown and explained. Since the PROSPECT project was focused on urban intersection scenarios with VRU participation, these scenarios are described in this paper. All results will be publicly available in the corresponding Deliverable later in 2019. As expected, the baseline performance was negligible in the newly addressed scenarios, whereas the prototype systems have shown the improvement towards a reaction in complicated urban accident scenarios impressively.

In Figure 11 the right turn scenario with the bicyclist is coming from behind is shown. This scenario is particularly challenging regarding the available field of view. The prototype vehicle had radar sensor to the back to be able to react properly and in time to this critical situation. The graph in the right of the figure provides an example of one of the right turns at 15 kph with AEB activation at 1.25 s before the collision. The programmed right turning trajectory for the test vehicle is represented by the dashed black line. The trajectory travelled by the Vehicle Under Test (VUT) is represented in red. The green dashed line represents the activation point of the AEB system. Only shortly after triggering the intervention the vehicle come to a complete stop, indicated by the end of the red solid line. The blue line is representing the trajectory of the bicycle dummy, which is displaced 3.5 m to the right of the VUT in this scenario. Both, the vehicle and the dummy, are time synchronized to meet at the calculated impact point and the right front of the vehicle where both trajectories cross. The front wheel of the bicyclist would collide with the front right corner of the vehicle. In the given representation, the solid lines (test vehicle and dummy) are referring to the corresponding GPS measurement point, which is the geometric centre of both bodies. The dotted red line represents the right edge of the vehicle’s body whereas the blue dotted line one is the left edge of the bicyclist dummy. The minimum distance between the vehicle and dummy at the end of the test is 0.82 m. The green X indicates the bicycle position at the moment of the AEB activation. The vehicle cornering speed was varied between 10 and 15 kph, whereas the bicyclist was constantly travelling at 15 kph. The warnings were issued in a range from 1.41 -1.58 s TTC (Time To Collision) and the following AEB intervention was triggered between 1.16 s and 1.32 s TTC.

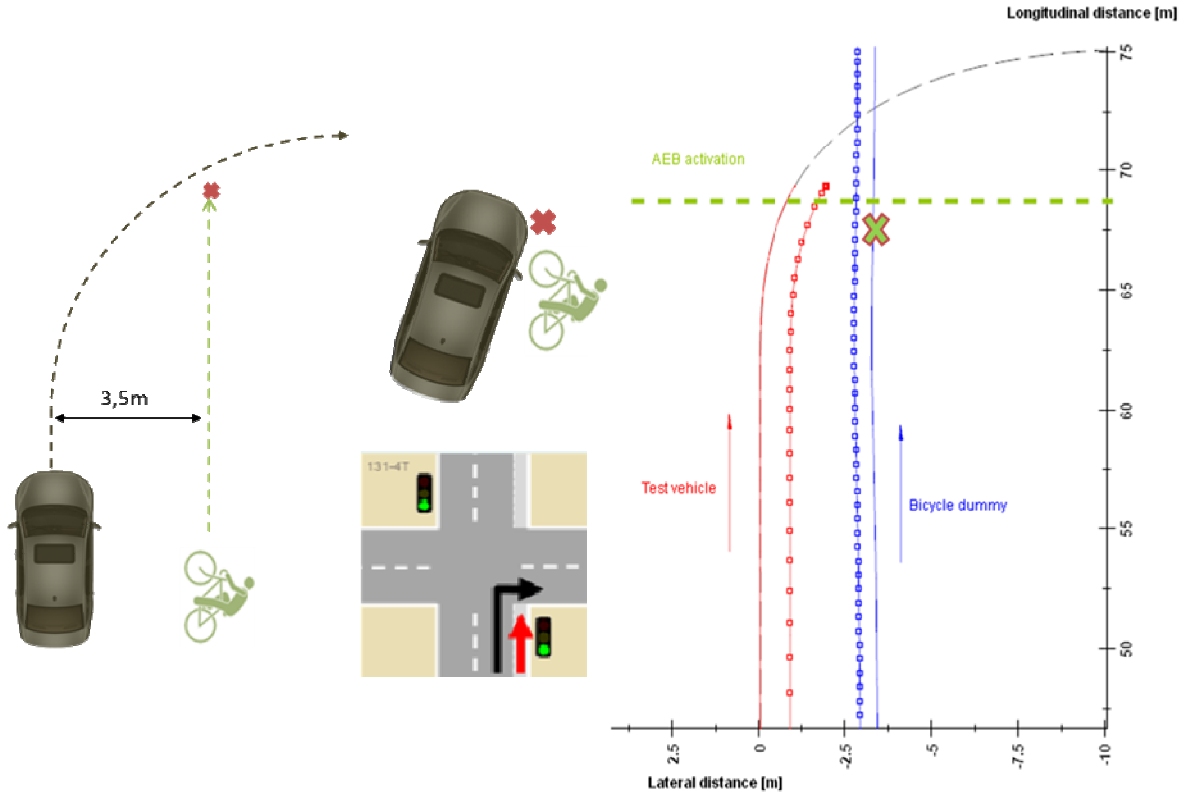


Figure 11: Right turning with bicyclist coming from behind.

In *Figure 12* the right turn scenario with the bicyclist is coming from the far side is shown. For this scenario braking before the turn was introduced. The VUT travels at 30 kph and before turning it decelerates to 20, 15 or 10 kph. The graph in the right of the figure provides an example of one of the right turns at 10 kph with AEB activation at 0.75 s before the collision. The bicyclist is coming from the right side riding next to the road three meters away from the targeted trajectory for the VUT (see *Figure 12*). The impact point for this scenario is the front wheel of the bicycle colliding with the centre of the front bumper of the VUT (50%). The bicyclist was constantly travelling at 15 kph. The AEB intervention was triggered between 0.72 s TTC for lower speeds and a maximum TTC of 2.3 s for higher cornering speed with avoiding all crashes.

In *Figure 13* the left turn scenario with the bicyclist is coming from the near side is shown. The VUT initially travels at 30 kph and before turning it decelerates to 20, 15 or 10 kph. The graph in the right of the figure provides an example of one of the right turns at 10 kph with AEB activation at 0.76 s before the collision. The bicyclist is coming from the left side riding at the road four meters away from the targeted trajectory for the VUT (see *Figure 13*). The impact point for this scenario is the front wheel of the bicycle colliding with the centre of the front bumper of the VUT (50%). The bicyclist was constantly travelling at 15 kph. The AEB intervention was triggered between 0.76 s and 1.06 s TTC avoiding all crashes.

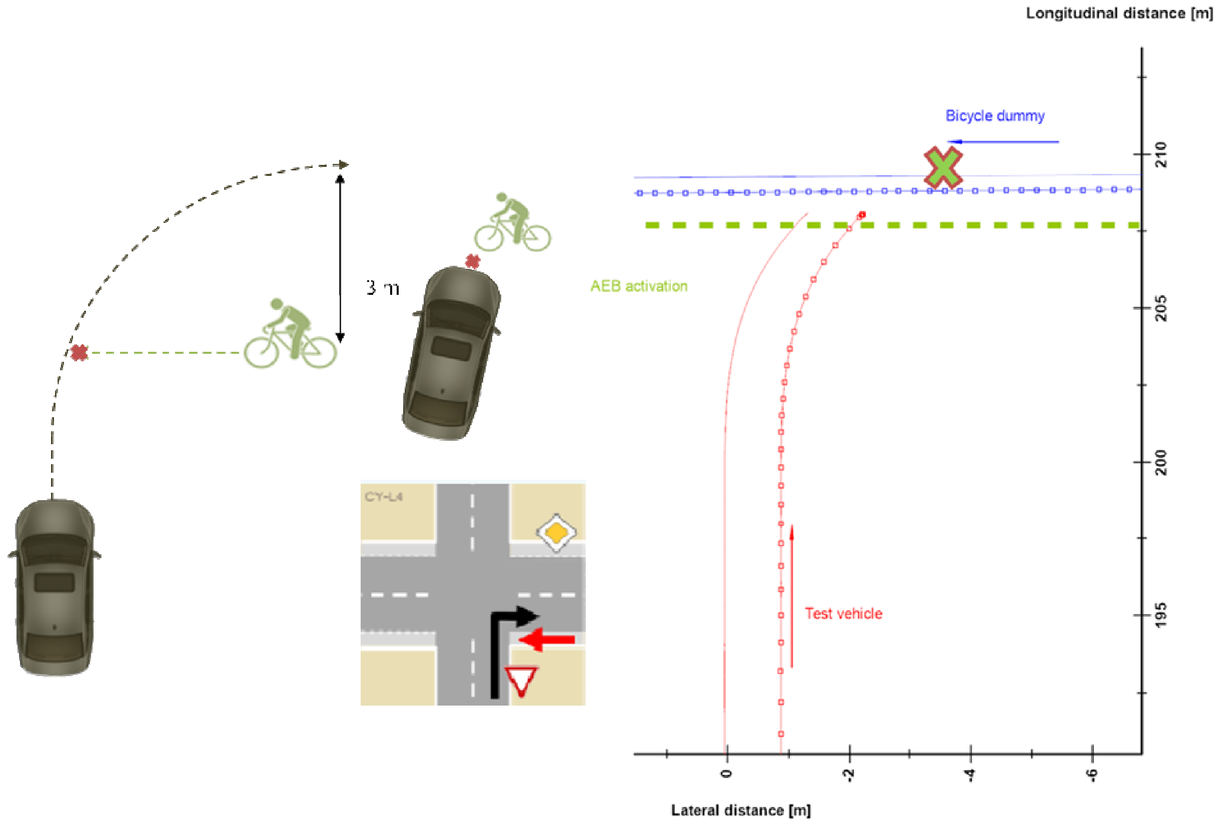


Figure 12: Right turning with bicyclist crossing from the near side.

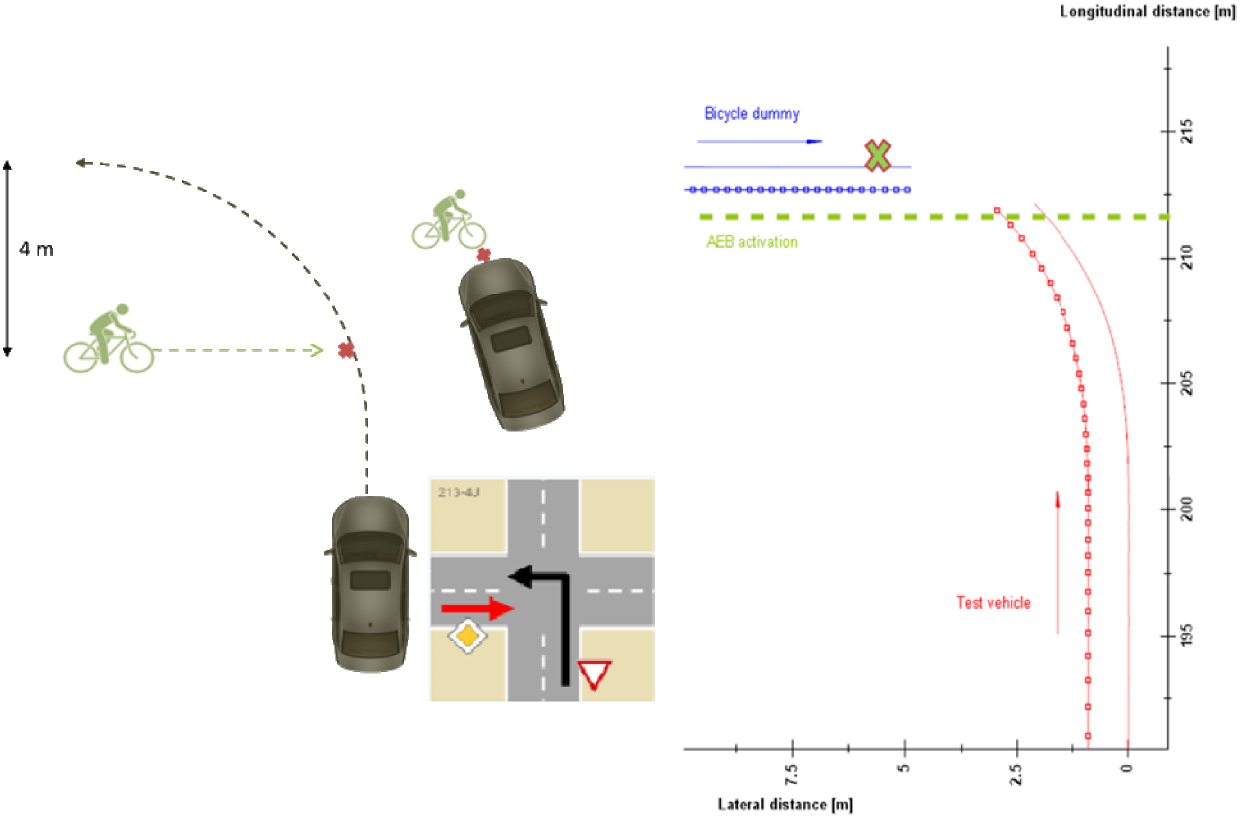


Figure 13: Left turning with bicyclist coming from the far side.

CONCLUSION

The testing activities have been carried out successfully and have met with the initially described objectives to improving current and developing novel active safety features to prevent accidents involving VRUs like pedestrians and bicyclists. The developed prototypes have performed according to expectations on their assigned test cases avoiding any kind of impact in all the tests. This achievement is mainly due to their advanced processing technology that allows identifying and assessing critical situations involving pedestrians more quickly.

In the roadmap of the European consumer testing agency Euro NCAP 2020 [8] intersection scenarios are planned to become a part of the future protocols. The research in the European funded project PROSPECT provides a first step towards addressing such scenarios in the near future. The findings and the proposed trajectories for negotiating a left and right turn are a solid basis for further research.

Potential is seen in control strategies for driving robots currently used for conducting those test cases. Since this has not been part of the scope yet, control strategies could be optimized for more detailed trajectories beyond the proposed three sections in this paper. In addition to that, the tuning for those driving tasks has to become more sophisticated. The project was focused on slow urban scenarios with a rather tight radius. In the future, interurban scenarios with higher curvatures and speeds might become a research focus. In this case, the trajectories need to be adapted in dependence of the desired speed profile. Apart from naturalistic driving studies in the field, specific studies on the test track could support a deeper insight in how trajectories are chosen depending on the circumstances and surroundings, e.g. obstructed views or the traffic situation.

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CONSUMER INITIATIVES TO IMPROVE CHILD SAFETY IN EUROPE

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ABSTRACT

Safe transport of children in cars is the joint responsibility of parents, child restraint suppliers and vehicle manufacturers. Responsible parents and caregivers must ensure that children are properly restrained in a correctly installed child restraint system (CRS) that is appropriate for the size and weight of the child. Child restraint suppliers make certain their products meet local regulations, offer adequate protection and can be fitted easily and correctly in all cars. Finally, it is the vehicle manufacturers' obligation to guarantee that children are as well protected as adults in the event of crash and that special any provisions needed for children are offered as standard. In practice, this joint responsibility leads to a set of complex interactions and a patchwork of solutions that make it difficult for average consumers to know how their child is carried in the best and most safe way.

In Europe, two independent consumer-oriented programmes work cooperatively to help consumers find the best answer for their unique situation. Child restraint testing is carried out by European consumer groups under the umbrella of International Consumer Testing and Research (ICRT) and the Automobile Clubs. The program publishes ratings based on standardised dynamic sled tests and an ease-of-use assessment, amongst other items. The European New Car Assessment (Euro NCAP) rates vehicle performance and equipment availability for new cars on the market. Its Child Occupant Protection assessment includes full-scale crash tests with child test dummies in child restraints and evaluates the availability and functionality of attachments and provisions for safe transport of children. Collectively, these programmes address one of the most pertinent and persistent challenges in child safety: the risk of misuse and incorrect installation of a child restraint system in a vehicle.

Child restraint testing is based on body-in-white setup applying standardised pulses. This set up only broadly approximates real life use in actual cars. In-vehicle testing comes closer to actual crash circumstances, but the result only applies to the combination of car model and CRS type. Both approaches are complementary, and both are needed to improve child safety in cars.

INTRODUCTION

Since May 2006, it has been compulsory to use safety belts and United Nations Regulation No. 44 type-approved child restraint systems in all vehicles in Europe [1]. It is also mandatory to use child car seats within the EU for children up to the heights of 1.35m or 1.5m - depending upon the country. Thanks to these laws and increased consumer awareness and compliance, child deaths in motor vehicle crashes have steadily declined over the last decades [2] (Figure 1).

Child Restraint Systems

The European Test Standard for Child Restraints [3] was introduced in 1982. From this time onwards, only seats displaying the European Standard orange label, indicating approval to UN Regulation No. 44, may be used or sold. Child restraint systems approved under R.44 are classified into five mass groups. For children up to 9kg they must be side- or rearward facing. Most common are rearward facing infant carriers up to 13kg. For the groups up to 18kg these child restraint systems have an integrated harness or shield system. The groups for heavier children up to 36kg mostly use the vehicle's safety belt for restraining. Approvals are based on several criteria, the foremost of which is the child restraint's performance in a simplified dynamic sled test, representing a frontal impact.

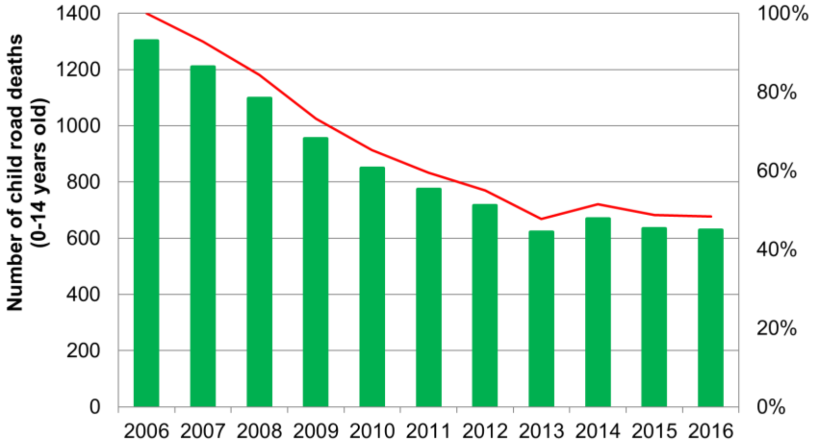

Figure 1. Development in the number of child road deaths in 27 EU countries over the period 2006-2016 (ETSC, [2])

UN Regulation No. 44 has been amended and updated many times since the 1980s. To facilitate correct installation of child restraints, the ISOFIX [4] standard for attachment points and connectors for child safety seats in passenger cars was introduced in 1997. ISOFIX became a standard in 2004, but only became mandatory in the EU for all new models launched from November 2012, and in all vehicles manufactured after November 2014 [5]. ISOFIX child seats can be either "Universal", approved for use in all vehicles that meet UN Regulation No. 14[1] [6] and No. 16 [7], or "Semi-Universal" or "Vehicle Specific" for use in specified vehicles.

The Reg.44 standard for child restraints can appear complicated from a consumer point of view. It covers belted, ISOFIX, Universal, Semi-Universal & Vehicle Specific approvals as well as having confusing overlaps in the weight groups. This has led to a kaleidoscopic of product offerings on the market that can easily cause parents to make the wrong choice for their child. Despite the availability of ISOFIX, there still are many mistakes made when installing a child restraint in the car or the child in the seat [8]. Furthermore, the standard allows forward facing transport as of 9 kg and does not encourage rearward facing transport of toddlers (>13kg), nor does it require child restraints to offer adequate protection in side crashes. These concerns, amongst others, have been addressed by the new UN Regulation No. 129 that came into effect in 2013 [9]. Even though i-Size clearly delivers superior child seats, UN Regulation No. 44 (currently R44.04) and UN Regulation No. 129 (currently R129/03) have been allowed to run side by side, at least for the time being. For the consumer, the situation on the ground therefore remains very confusing.

For more than 50 years, consumer groups under the umbrella of International Consumer Research and Testing (ICRT) and Automobile Clubs have been testing child restraint systems in order to guide consumers into buying the best seat for their child. Initially run as separate programs in various countries, they joined forces in 2003 by forming the European Testing Consortium (informally referred to as "ETC"). The main partners are ADAC (D), ÖAMTC (AT) and TCS (CH) on behalf of the automobile clubs and Stiftung Warentest (D), Which (UK), Consumentenbond (NL), Test Achats (B) and Que Choisir (F). The program is fully independent and funded by partners. Test results are published by more than 30 organisations across Europe (and beyond) in different presentation formats (Table 1). Twice a year a batch of new CRS models is tested, and the results are published by the end of May and October. On average some 50 models are published each year. Benchmarking testing has become a powerful tool to drive improvements in CRS design, as a good ETC rating is a must for child seat manufacturers to be successful in the market.

Passenger Cars

In Europe a type approval is applied by national authorities to certify that a vehicle meets all EU safety, environmental and conformity of production requirements before authorising it to be placed on the EU market. As the EU is a Contracting Party to the 1958 Agreement of the World Forum for Harmonization of Vehicle Regulations, it generally applies the technical requirements of the UN ECE to verify compliance with safety rules. This is also the case for child occupant protection, which is ensured directly via production requirements on seat-belts, ISOFIX anchorages and top-tethers in Regulation No. 14/145 and No. 16, and indirectly (as testing does not involve child dummies) through the application of mandatory crash front and side impact crash tests for the whole vehicle.

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[1] In 2017, ISOFIX and child restraint system anchorage provisions were separated from UN Regulation No. 14 and included in Regulation No. 145.

Table 1.
Publishing partners distributing ETC test results in European countries (2018)

Country	Partner	Country	Partner
Austria	ÖAMTC, VKI	Luxembourg	ACL
Belgium	Test Achats/Test Aankoop	Netherlands	ANWB; Consumentenbond
Bosnia & Herzegovina	BIHAMK	Norway	Forbrukerrådet
Croatia	HAK	Poland	Świat Konsumenta
Czech Republic	dTest	Portugal	ACP; DECO Pro Teste
Denmark	FDM; Forbrukerrådet	Romania	APC Romania
Finland	Autoliitto; Kuluttaja	Slovenia	AMZS; ZPS
France	Que Choisir	Spain	RACC; RACE; Oficina de Co. Universitaria
Germany	ADAC; Stiftung Warentest		
Hungary	Kosár; Magyar	Sweden	Råd & Rön; Motormännen
Italy	Altroconsumo	Switzerland	TCS
Lithuania	LNVF	United Kingdom	Which?

Since 1997, Europe's type approval system is complemented with the new car assessment programme Euro NCAP, which provides motoring consumers with a realistic and objective assessment of the safety performance of the most popular cars sold in Europe [10]. Euro NCAP encourages manufacturers to exceed the legal requirements by applying more stringent and/or additional test conditions and by extending the assessment to new areas of vehicle safety. At present the organisation has 12 members representing the citizens and consumers in the whole of Europe. These include the Member State governments of the United Kingdom, Germany, France, Sweden, the Netherlands, Luxemburg and the regional government of Catalonia; the International Automobile Federation FIA; motoring clubs ADAC and ACI; International Consumers Research and Testing; and the Motor Insurance Centre Thatcham Research. In the 22 years of its existence, Euro NCAP has published ratings on over 700 different vehicles, including superminis, family cars and MPVs, roadsters, SUVs, pick-up trucks, hybrids and full electric vehicles.

From 2003, Euro NCAP has specifically addressed the protection of children in the event of a crash. The child occupant protection star rating aims to help consumers choose the best car for their family, to motivate all car manufacturers to deliver improved child protection and to facilitate a better dialogue between car manufacturers and child restraint suppliers. In 2009, the Child Occupant Protection rating became part of the overall safety rating, making a good child protection score a prerequisite for 5 stars [11].

METHODS

Consumer test programmes such as ETC and Euro NCAP give consumers the ability to hold manufacturers to account, by giving them more control over the product which they need. They make sure that markets work properly so that competition between manufacturers drives down prices and sparks innovation from which consumers benefit. Central to their mission is to provide data and tools to inform, educate and, if necessary, support consumers when they must make difficult choices, such as buying a child seat for their firstborn, or the safest car for the family.

Both consumer programmes have a wide scope, covering more aspects than what is legally considered, to reveal hidden product properties and to promote best practice. They share an underlying philosophy that children should benefit from at least the same level of protection as adults/their parents. Despite their complex technical assessment, ETC and Euro NCAP have adopted a simple communication language to explain the results, using "stars" or easy to understand labels. Their test methodologies are regularly reviewed and updated considering regulatory and market changes. In the case of ETC, industry is consulted in hearings at Stiftung Warentest (the so-called "Fachbeirat"), whereas Euro NCAP has invited vehicle manufacturers and seat suppliers to its working group on child safety.

Child Restraint System Test Methodology (ETC)

The main aim of the ETC test is to inform parents of the best solution to transport their child: the child seat that offers the best protection, is easy to handle, comfortable for the child and is free from hazardous substances. For this purpose, ETC has developed its own test methodology that assesses (1) dynamic performance, (2) ease-of-use, (3) ergonomics and (4) the presence of hazardous materials (Figure 2). Seats from all five mass groups (0, 0+, I, II, III) in UN Regulation No 44 and all size ranges in UN Regulation No. 129 are tested. If a seat covers several mass groups, a wide size range or different installation modes, all modes are tested and rated. The test results are combined into one overall rating per product. Where there are several installation modes, the overall rating will be based on the worst-case performance of the product. However, because it is expected that ISOFIX products will usually be used in ISOFIX mode, ISOFIX results will be prioritised over belted results. A well-known example of this “worst-case performance” policy is that booster seats with detachable backrests are unable to score well owing to their lack of side impact protection when used as cushion only.

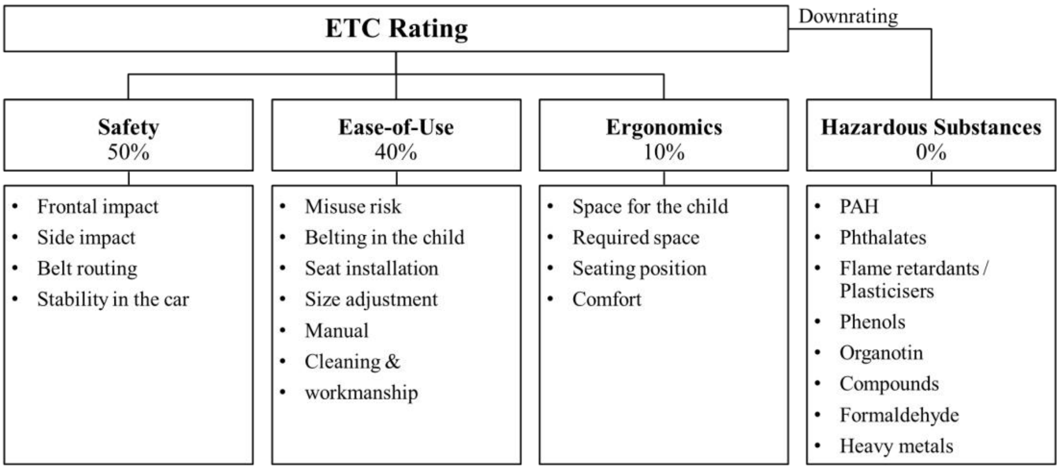

Figure 2. ETC Test overview (2018)

To ensure that results are representative, test samples are exclusively procured in retail point of sales, without the prior knowledge of the child seat supplier. From time to time, the testing procedure and the assessment are adapted based on the latest findings. For example, in 2007, the P-series dummies (except P10) were replaced by Q-series dummies; in 2011, the test of hazardous substances was implemented; and, in 2015, a side impact test with an intruding door, the Q10 dummy and Q3 abdominal load sensors were introduced.

Dynamic tests The latest dynamic test matrix includes fontal impact tests on Body-in-White (BIW), side impact tests on a test bench derived from Regulation No. 129, and an assessment of belt routing and seat stability in the car (Figure 3). A summary of tests is given in Table 2.

Table 2.
Summary of ETC Child Restraint Dynamic Tests & Assessment (2018)

Load Case	Test Parameters	Assessment
Frontal impact	• VW Golf VII BIW – child seats on rear seat • VW Golf VII ODB B-pillar pulse (Euro NCAP) • All available installation and adjustment possibilities and child sizes (5 tests on average)	• Q-dummies • Head, neck, chest and abdominal loads (Q3) • Belt routing • Seat stability
Side Impact	• Regulation No. 129 bench, 80° impact angle • VW Golf VII AE-MDB barrier pulse (Euro NCAP) • Intrusion depending on installation and adjustment possibilities and child sizes (3 tests on average)	• Q-dummies • Head, neck and chest loads

The dynamic tests are more demanding than legally required, thereby highlighting the extra protection the seat offers. The crash severity is comparable to Euro NCAP full scale tests, which nowadays are survivable types of crashes. All products tested are measured to the same yardstick irrespective to their (Regulation No. 44 or No. 129) approval. Dynamic tests are carried out at ADAC Technical Centre and the result contributes to the overall score with a weight of 50%.

Ease-of-use test In the ease-of-use tests, several handling aspects are assessed. These include misuse risk, the ease of strapping the child in the seat, ease of seat installation (by experts and laymen) and size adjustment, clarity of the user’s manual and cleaning & workmanship aspects. In the latest version, three car models are used: Opel Adam 3-door, Golf VII 5-door and Ford C-Max. Ease of use assessments are carried out at ÖAMTC (Vienna) and the result has a weight of 40% in the overall score.

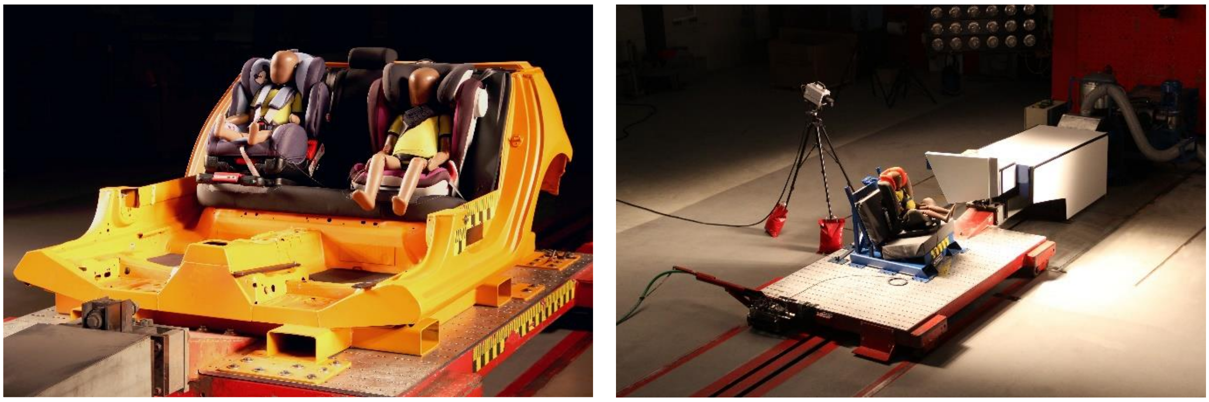

Figure 3. ETC front (left) and side (right) impact test © 2018 ADAC

Ergonomics test Expert and layman tests are carried out to verify the space available for the child, the required space inside the vehicle for installation, the resulting seating position, and comfort. The Opel Adam 3-door, Golf VII 5-door and Ford C-Max are used for these assessments as well handling dummies and actual children. Ergonomics checks are carried out at ÖAMTC and TCS and the result has a weight of 10% in the overall score.

Hazardous substances test Finally, all parts of the seat that are in contact with the child are screened for the presence of the following substances: Polycyclic aromatic hydrocarbons (PAH, based on the AfPS GS 2014:01 PAK document), Phthalates (based on Regulation EC No. 2005/84, Directive 76/769/EEC, Oeko-Tex Standard 100, and RAL-UZ textile toys), Flame retardants (based on Oeko-Tex Standard 100, EN 71-9 and Directive 2014/79/EU), Phenols (based on Oeko-Tex Standard 100), Organotin compounds (based on Oeko-Tex Standard 100), Formaldehyde (based on EN ISO 14184-1 and EN 71-9), and Heavy metals (based on EN 71-3). The findings do not contribute directly to the overall score but may be used to downgrade the overall score in case of pollution.

Child Occupant Protection Assessment Methodology (Euro NCAP)

Up until the nineties, car manufacturers relied on the makers of child restraints to provide protection for children in cars. Very few offered child restraints through their dealerships or provided any recommendation to their customers, and there were almost no special provisions in the vehicle, over and beyond the basic requirements in Regulation No. 14/145 and No. 16, for the safe transport of children. It has become clear, however, that there are many aspects of child protection which cannot be influenced by the child restraint manufacturer alone and which require action on the part of the car manufacturer as well. For this reason, Euro NCAP developed a specific assessment of the vehicle's ability to safely transport children.

From the beginning, the Euro NCAP Child Occupant Protection (COP) rating focused on three main elements: (1) the protection offered in front and side crash tests, (2) the interface between vehicle and child seat and (3) the special provisions for children in cars (Figure 4). The test results are converted into item scores, which are summed to form the COP score. Up until 2008, this score was communicated as a separate star rating. From 2009, the COP score, along with the Adult Occupant, Pedestrian Protection and Safety Assist scores, has been used to calculate the overall safety rating of the vehicle. Euro NCAP most commonly follows a VIN selection method [12] to source test vehicles, while child seats for testing are provided by either supplier or manufacturer.

Dynamic tests The frontal off-set deformable barrier and the side mobile deformable barrier test have formed the backbone of Euro NCAP's crashworthiness assessment since the start of the programme in 1997. Initially, the 3-year old and 18 months old P-series dummies were used to check dynamic performance. As test results improved over time, the focus shifted to the protection of older children. Since the latest revision (2016), the more biofidelic 10-year old and 6-year old Q-series dummies are placed on the rear seat (Q10 behind the passenger in the frontal impact test, behind the driver in the side impact test). The Q6 dummy is seated on booster seat appropriate for its mass or stature and recommended by the vehicle manufacturer. The Q10 dummy is placed on a booster cushion from a list of preselected products, even if a high back booster is recommended by the vehicle manufacturer in the user manual. The reason for this somewhat unusual set-up is the low use rate of high back boosters in real-life for children of 8 years and up. The use of the booster cushion will verify if adequate protection is offered by the vehicle's restraint systems alone.

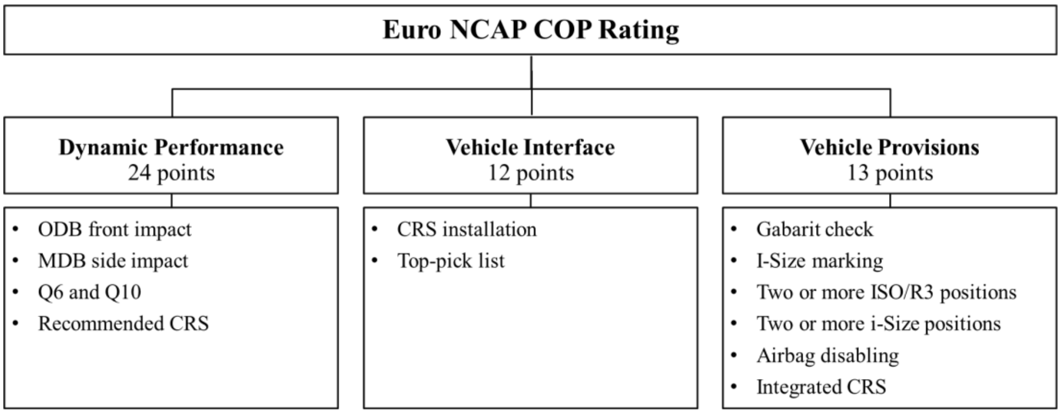

Figure 4. Euro NCAP Child Occupant Protection overview (2018)

Overall, for a good dynamic score in Euro NCAP's tests, vehicle manufacturers must ensure children are well protected by providing, amongst other things, robust seat attachments, good belt geometry and head protection. They also must correctly inform parents about the best child seat to use for all ages and ensure that these seats are available on the market.

A summary of the Euro NCAP dynamic tests & assessments is given in Table 3.

Table 3.
Summary of Euro NCAP Dynamic Tests & Assessment (2018)

Load Case	**Test Parameters**	**Assessment**
Frontal impact (ODB, 64 km/h)	• Instrumented Q6 in recommended booster seat (ISO 13499, position 4) • Instrumented Q10 on booster cushion from top-pick list (ISO 13499, position 6)	• Q6 and Q10 dummies • Head, neck, chest* • Contact, excursion, ejection
Side Impact (AE-MDB, 50 km/h)	• Instrumented Q6 in recommended booster seat (ISO 13499, position 6) • Instrumented Q10 on booster cushion from top-pick list (ISO 13499, position 4)	• Q6 and Q10 dummies • Head, neck and chest* • Contact, excursion, ejection

** Criteria and limits are included in Table 7 and 8.*

Vehicle interface assessment The original vehicle marking and vehicle interface requirements - such as clear vehicle handbook instructions, belt length and correct marking of ISOFIX attachment points – were replaced in 2013 by a Child Seat Installation Check, in which a selection of popular products is used to assess the vehicle's ability to safely and correctly accommodate child seats.

The so-called top pick list contains a sample of widely available, well performing (i.e. ETC rated "good") child seats that represent most common types of products available on the European market. The list is checked annually and updated if seats are no longer available on the market. The installation procedure focusses on typical and known incompatibilities that often lead to misuse in the real world, such as insufficient seat belt length for rearward facing seats; instability caused by child seat contact with head restraint, C-pillar or roof; inaccessible ISOFIX anchorages; and insufficient floor strength for a support leg. Seating positions where, for any reason, child restraints cannot be safely installed should be clearly identified by the manufacturers in the user's manual.

Vehicle based assessment Not all cars offer the same provisions especially when more than one child seat is required. Euro NCAP rewards vehicle manufactures that have clearly designed the vehicle with families in mind and apply best practice solutions. To be eligible for scoring, the information provided in the user's manual should clearly state what is and what is not possible in terms of installing child restraint systems on the different seating positions in the vehicle.

Additional points are available for extra seat belt length, meeting extended i-Size marking requirements, the availability of two or more ISO/R3 positions and offering two or more i-Size seating positions in the vehicle. Similarly, points can be rewarded for automatic and manual Passenger Airbag disabling switches with correct warning marking, and for the installation of one or more integrated child seats as standard.

RESULTS

Trends in Child Restraint System Performance

Since 2003 more than 700 different child seat models have been tested and rated by ETC. Currently about 75% of the tested products are rated "very good", "good" or "satisfactory". All of them far exceed the legal requirements. An overview of the overall ratings of all tested seats since 2003 is displayed in Figure 5. From the figure it can be observed that the number of good performing seats has increased over the last years. It is especially encouraging that two thirds of the tested products achieve a "very good" or "good" safety score even though the ETC frontal impact test energy exceeds the approval test by 50% and side impact testing is mandatory only for products that are approved to Regulation No. 129. This means that most of the seat manufacturers respect the requirements of the consumer test for the development of their products.

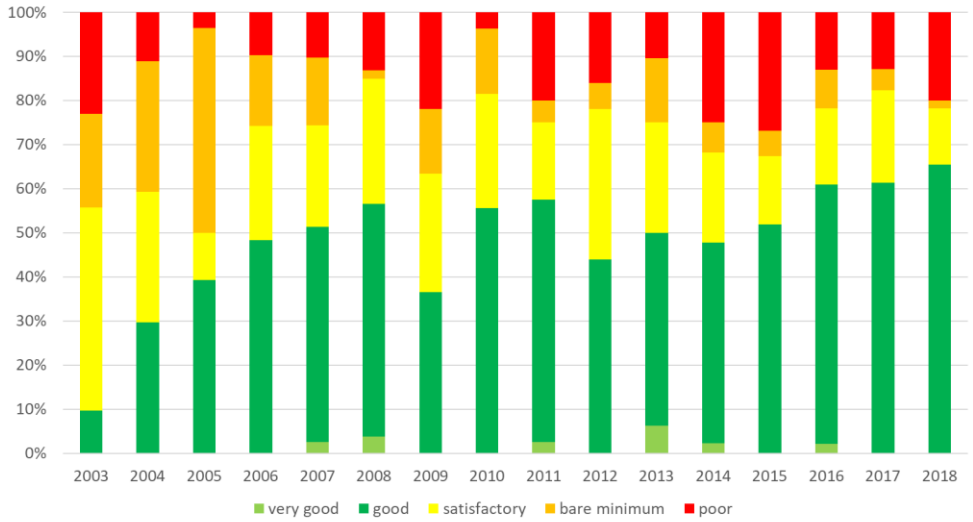

Figure 5. ETC Overall Child Seat Rating results since 2003

Unfortunately, every year there are a few seats tested that fail the tests and cannot be recommended to the consumer. The detailed reasons for the poor safety ratings are listed in Table 4 below.

Table 4.
Problems found in ETC Safety Tests (2015-2018)

Rating year	Total number of seats	Seats with one or more safety critical problem	Description of the problem
2015	52	1 (2%)	• The seat shell partially detached from its base in frontal impact test
2016	46	4 (9%)	• In two of the seats the dummy loadings indicated an increased high injury risk in case of a side impact and the head was not properly contained within the seat • One seat shell partially detached, and a second seat fully detached from its base in frontal impact test
2017	62	6 (10%)	• In two of the seats the lap portion of the seatbelt heavily cut into the abdomen of the dummy during the frontal impact test • In one seat the smallest dummy was ejected during the frontal impact test • One seat shell fully detached from its base in frontal impact test • On one seat one ISOFIX attachment opened within the frontal impact test • One seat was rated poor due to the lack of side impact protection
2018	55	3 (5%)	• In two of the seats the lap portion of the seatbelt heavily cut into the abdomen of the dummy during the frontal impact test • In one seat the smallest dummy was ejected during the frontal impact test • One seat shell fully detached from its base in frontal impact test

Side impact performance was improving long before the side impact sled test became mandatory in legislation (first introduced for Regulation No. 129-approved products in 2013; the share of Reg. 129-approved products tested by ETC test can be found in Table 5). Since 2015, only three of the 215 tested models were rated poor because of the high injury risk during the side impact test. An overview of the safety ratings of all tested seats since 2003 can be found in Figure 6, with an overview of the side impact ratings in Figure 7.

Table 5.
Share of products approved under "i-Size" Regulation No. 129 (2013-2018)

Rating year	Total number of seats	Number (share) of i-Size seats
2013	48	0 (0%)
2014	44	1 (2%)
2015	52	6 (12%)
2016	46	13 (28%)
2017	52	18 (29%)
2018	55	28 (51%)

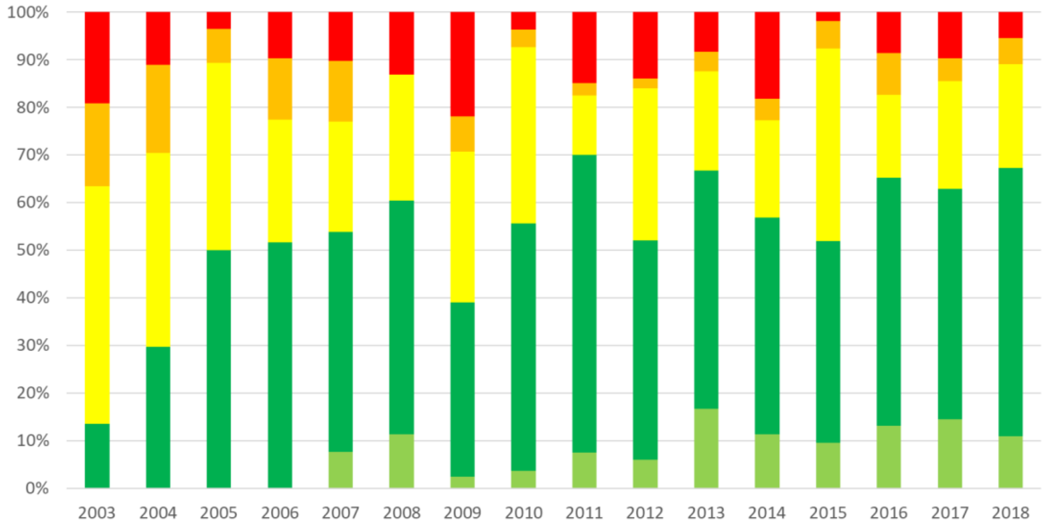

Figure 6. ETC Safety ratings of all tested seats since 2003

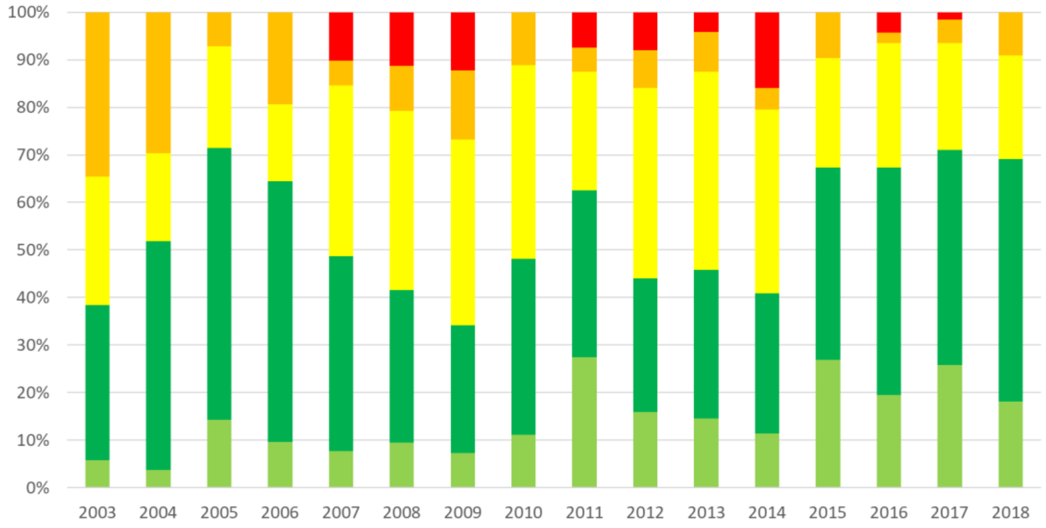

Figure 7. ETC Side impact scores of all tested seats since 2003

Although a rare occurrence, in 2016 the overall rating of one seat was downgraded because of a poor ease of use score. Tightening the integral harness took excessive force and several separate accessories were required to adapt the seat to the child's correct weight. Both facts would result in a high risk of misuse and due to this there is a high potential risk of an inadequate protection in case of a crash. Beside this outlier, the ease of use ratings of most of the seats were favourable. The ease of use ratings of all tested seats since 2003 can be found in Figure 8.

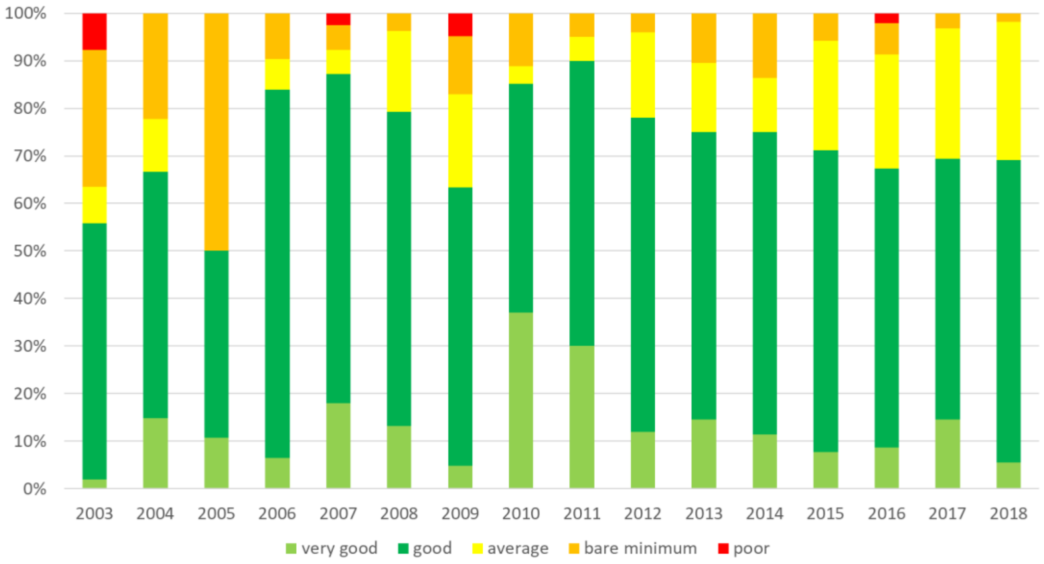

Figure 8. ETC Ease of use ratings of all tested seats since 2003

Since 2011 all fabrics of the CRS that are in direct contact with the child are screened for hazardous substances. If the rating of this criterion is "average" or better, it does not influence the overall rating. A "bare minimum" rating leads to a gradual downgrading of the overall result, and a "poor" rating will downgrade the overall rating to poor. Figure 9 summarises the hazardous substances ratings of all tested seats. After the "safety" rating, the hazardous substances rating is the second most common reason for a poor recommendation for a child seat.

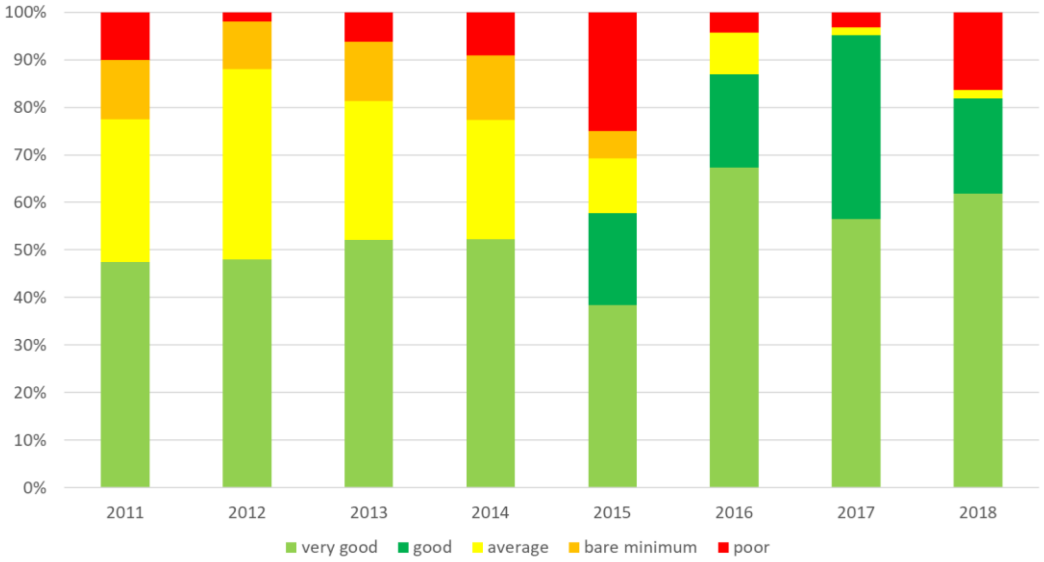

Figure 9. ETC hazardous substances ratings since the introduction in 2011

Trends in Child Occupant Protection

The start of Euro NCAP in 1997 coincided with the introduction of European whole vehicle type approval crash tests, leading to fast improvement of vehicle crashworthiness in the market. Euro NCAP's first COP test protocol strongly emphasised the availability of ISOFIX attachment points - accessible and clearly marked. This served as a market catalyst until ISOFIX lower anchorages and top tether attachments finally became mandatory for all vehicles in 2014 (Figure 10).

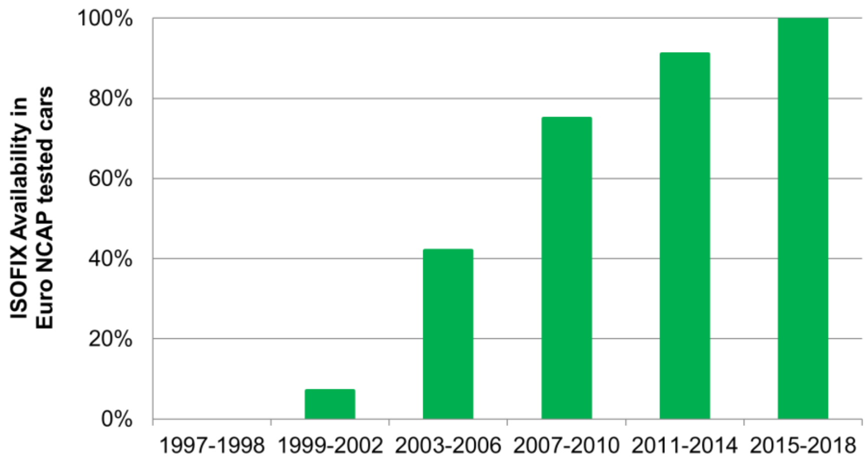

Figure 10. Share of Euro NCAP rated cars, standard equipped with ISOFIX.
From 1997 until 2003, Euro NCAP evaluated but not rated child seat performance.

The most challenging part of the early protocol were the dynamic crash tests. To mitigate any risk, manufacturers settled on a handful of recommended child seats, such as the Britax-Römer Baby Safe and Duo Plus, that were known to meet Euro NCAP's labelling requirements and had few test issues. Other requirements such as the availability of integrated child seats and automatic airbag disabling switches were mostly ignored. Overall, however, significant progress was made over the first decade after the introduction in 2003 (Figure 11).

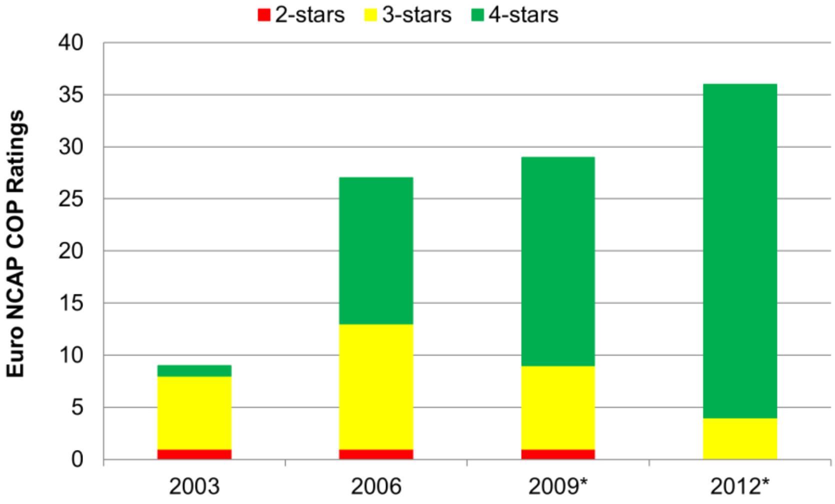

Figure 11. COP Ratings over the years. *For 2009 and 2013, COP percentage scores (used to compute the overall rating) were converted to COP stars using the original thresholds.

From 2013, the assessment of child occupant protection in Euro NCAP has taken a different direction. The objectives of the revision were twofold: firstly, to better address child seat misuse and handling issues through CRS installation checks and the promotion of i-Size; and secondly, to enhance the test relevance to real-world by including more biofidelic dummies and addressing more child ages.

Euro NCAP collaborated with ETC to select common installation seats with different characteristics: belt mounted, belt mounted with base & support leg, ISOFIX mounted with base & support leg rearward facing, ISOFIX with Top-tether mounted, ISOFIX mounted forward facing as well as i-Size variants [13]. Each car model has been assessed by installing each seat (in different modes if applicable) on all eligible seating positions in the vehicle.

Table 6 shows the number of vehicles in which one or more critical safety problems were found during the CRS installation check in recent years. A "safety critical problem" points towards an incompatibility between the CRS and the seating position in the vehicle, which could lead to incorrect installation or misuse. Overall, installation problems were found predominantly with universal, belt mounted child restraints, specifically on the front passenger and rear centre seating positions (Figure 12).

Table 6.
CRS Installation Check Results (2013-2018)

Rating year	Total number of cars*	Cars with one or more safety critical problem	Affected seating positions
2013	32	7 (22%)	Front, 2nd row centre and 2nd row outboard
2014	41	7 (17%)	Front, 2nd row centre and 2nd row outboard
2015	42	6 (14%)	Front, 2nd row centre and 2nd row outboard
2016	17	6 (35%)	Front, 2nd row centre and 3rd row
2017	59	20 (34%)	Front, 2nd row centre, outboard and 3rd row
2018	20	3 (15%)	Front, 2nd row outboard and 3rd row

**Excluding twins, partners, dual ratings and re-assessments.*

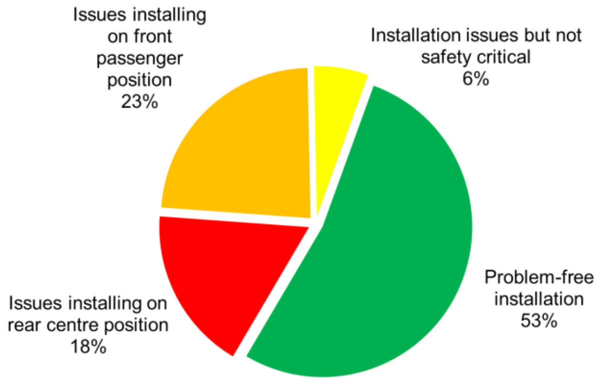

Figure 12. Issues encountered during installation of Universal CRS in Euro NCAP rated cars (N=17, 2016)

The decision to reward vehicle manufacturers for offering two or more i-Size positions has had a profound impact on the availability of the voluntary standard in new cars (Figure 13) in recent years. Within two years of the coming into force of Regulation 129 Phase 1 in July 2013, most cars tested offered two outboard i-Size compatible positions and, increasingly, the front or centre rear seats are also covered.

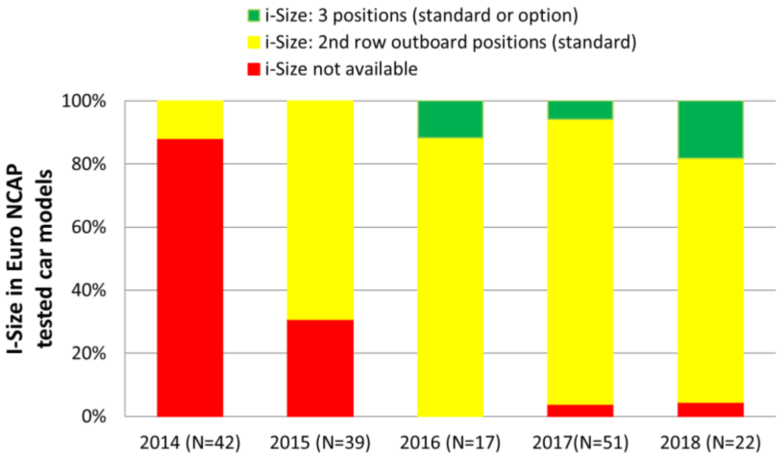

Figure 13. i-Size positions in Euro NCAP tested cars, from 2014 to 2018

If, for any reason children are obliged to travel in the front passenger seat in their child restraint system, it is important (and required by law) that the airbag is disabled. Euro NCAP also encourages automatic disabling of passenger airbag in case a child is detected. However, over the years most vehicle manufacturers have offered either a manual switch or a dealer-disconnect option instead. From 2016 onwards, several cars have been evaluated that offer automatic switches based on pressure-sensing technology in the passenger seat (Figure 14). Euro NCAP

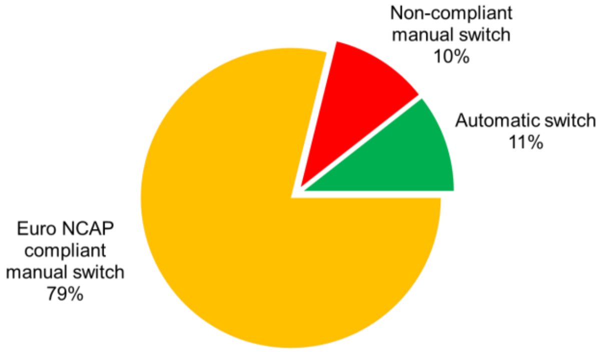

Figure 14. Airbag disabling switches in Euro NCAP tested cars (2016-2018, N=104)

has recognised the need to introduce a standard method of assessment for automatic passenger airbag disabling systems and introduced a laboratory test to check if the following requirements are met:

- Airbag is OFF when using a Rearward Facing CRS.
- Airbag is ON for a 5th percentile (female) occupant and above.

The responsibility for the remaining cases (forward facing CRS or child alone) is for the OEM, and different strategies are allowed. The requirements and test matrix covering a variety of possible occupant sizes and installation modes are listed in Euro NCAP Technical Bulletin 23 [14].

The availability of integrated seats as an option, let alone as standard, remains poor, despite the incentive that Euro NCAP has put in its test protocol. Primarily, large Volvo cars, including the S90/V90 and XC90, were equipped but only as optional equipment. Costs and conflicting design requirements are often cited as the main causes why integrated seats are not more common.

Finally, the new dynamic assessment using the Q6 in a booster seat and, in particular, the Q10 seated on a cushion has brought some new challenges for vehicle and CRS manufacturers [15]. Of the 114 models rated between the start of 2016 and the end of 2018, in 102 cases (89%) the Q6 was placed in a Britax-Römer supplied seat, most cases the KIDFIX XP (SICT) original or manufacturer branded. The seat had a reliable performance in both front and side impact crash tests, which explains its popularity amongst vehicle manufacturers. In general, Q6 results in Euro NCAP crash tests are good (Table 7), demonstrating that a child properly restrained in a CRS rated good by ETC and mounted correctly in the car with ISOFix/i-Size attachment points, is delivering a safe solution. In frontal impact, there were no instances recorded of hard contact with the vehicle interior, ejection or seat failures, and only in one case the Q6 submarined due to large forward rotation of the seat. In side impact, a few cases of hard contact where observed but only in one case did this result in the HIC value grossly exceeding the limit.

Table 7.
Euro NCAP COP Dynamic Test Results for Q6 Dummy (2016-2018)

Criterion	**Performance Limits**		**Dummy Values**		
	Higher	**Lower**	**Average**	**Min**	**Max**
Frontal impact (average B-pillar deceleration, 39g)					
HIC_{15} (with hard contact)	500	700	372	148	913
Head Resultant 3ms Acceleration (g)	60	80	59	40	91
Head Excursion (mm)	-	550	197	51	549
Neck Tension Fz (kN)	1.7	2.62	1.8	0.7	3.0
Neck Extension My with contact (Nm)		36	14	6	36
Chest T4 Acceleration (g)	-	-	47	35	61
Chest Deflection (mm)	30	42	20	13	26
Side impact (average B-pillar acceleration, 29g)					
HIC_{15} (with hard contact)	500	700	136	1	4675
Head Resultant 3ms Acceleration (g)	60	80	35	15	85
Neck Resultant Force (kN)		2.4	0.9	0.3	2.2
Chest T4 Acceleration (g)		67	32	13	54

The Q10 dummy more often caused issues during testing, revealing shortcomings in the rear seat restraint design for taller children. The dummy is placed on a booster cushion using the adult belt. The purpose of the cushion is to raise the seating position and improve the belt fit; the specific design of the cushion is less relevant however. For this reason, the cushion is most often selected from a list of available products.

In frontal impact, poor belt geometry may cause the belt to slide off the shoulder or towards the neck. In some cases, this has led to the dummy becoming unrestrained during the crash or to the dummy submarining, both of which incur a penalty. The Q10 dummy shoulder and barrel-like chest design is partly to blame for this behaviour and Euro NCAP has adopted suggested modifications to the dummy hardware to address this [16].

In side impact, both head contact with the C-pillar and head curtain bottoming out has been observed with high resulting HIC and Head Resultant Accelerations. An overview of Q10 dummy results can be found in Table 8.

Table 8.
Euro NCAP COP Dynamic Test Results for Q10 Dummy (2016-2018)

Criterion	Performance Limits		Dummy Values		
	Higher	Lower	Average	Min	Max
Frontal impact (average B-pillar deceleration, 39g)					
HIC_{15} (with hard contact)	500	700	254	111	908
Head Resultant 3ms Acceleration (g)	60	80	50	36	94
Head Excursion (mm)	450	550	184	40	551
Neck Tension Fz (kN)	1.7	2.62	2.1	1.5	4.1
Neck Extension My with contact (Nm)	-	49	13	5	34
Chest T4 Acceleration (g)	41	55	37	27	53
Chest Deflection (mm)	-	-			
Side impact (average B-pillar acceleration, 29g)					
HIC_{15} (with hard contact)	500	700	211	2	2245
Head Resultant 3ms Acceleration (g)	60	80	49	14	109
Neck Resultant Force (kN)	-	2.2	0.7	0.4	2.32
Chest T4 Acceleration (g)	-	67	50	17	88

DISCUSSION

Nowadays the ETC rating can make or break a product’s success on the market. A good rating can boost child seat sales, whereas products that have failed in the test have been recalled or even withdrawn from the market in the past. For this reason, a good ETC child seat rating is a design aim for many seat manufacturers. The impact of the ETC programme can be explained by its huge outreach to European consumers, but also because the tests are more realistic, more complete and more demanding than the basic regulatory tests. The consortium stands by its decision to withhold the exact details regarding the way that the rating is calculated to ensure that products are not optimised for the test. In other aspects, such as test procedure, supplier meetings, Fachbeirat, etc., ETC is committed to an open and transparent process.

In many cases ETC tests have revealed shortcomings in the regulatory tests and its finding have contributed to enhancements in type approval requirements. A good example is side impact protection, that has been addressed in the ETC test for many years. Consequently, most products on the market provided adequate side protection well before side impact test specifications and requirements were introduced in UN Regulation No. 129. More recently, the consumer groups have raised concerns about the absence of limits on neck tension force in Regulation No. 129, especially for babies in lie-flat infant carriers [17]. Likewise, they have observed inconsistencies with the abdominal load sensor specified in Regulation No. 129 which at present seems to be unable to distinguish between well and poorly designed child seats.

On the downside, ETC has been criticised for its favourable position regarding so-called booster shield systems, that do not require a belt harness to restrain the child. Many international experts do not consider booster shield systems appropriate crash protection for children, as crash investigations have documented ejections, excessive excursions, and shield-contact injuries in rollover, side and frontal crashes. ETC has adopted the abdominal load sensor in its recent tests to improve its assessment of injury risk in the abdominal region, but many still believe that shield systems should not be given the benefit of the doubt, even if laboratory test results indicate good performance. This situation is in stark contrast with the consortium’s red line on booster seats with removable backrest, that are always penalised for the perceived lack of side impact protection.

Euro NCAP is one of a limited number of NCAPs around the world that test child restraint systems in full-scale vehicle test conditions. Whereas the focus of ETC is on improving CRS performance, Euro NCAP addresses the car design, equipment and the interface with child restraint systems. A strong link between the programs has been forged to improve the situation on misuse of child restraints, where Euro NCAP verifies the problem-free installation of popular, well rated child restraints. Incentives for vehicle provisions such as ISOFIX and airbag disabling switches have been effective and their availability as standard has increased significantly as a result. But child occupant protection is only one of four pillars in the Euro NCAP star rating and underperforming in this area can lead to a lower overall rating or jeopardize investments in the other areas of safety. For this reason, Euro NCAP makes its test and assessment protocols public, including the criteria and their limits, generally with a short but adequate lead-time.

A key principle behind the COP assessment is that vehicle manufacturers should take responsibility for safe transport of adults and children alike. Among other things, this means that manufacturers must recommend the best child seats for their car for testing. In practice, this leads to a bias amongst the tested child restraint systems towards high-end products that are usually available Europe-wide and stable in the market. Normally, they only represent a small share of the sales and the dynamic results may be less useful to buyers of child restraints for that reason.

The shift in focus from toddlers to taller children in Euro NCAP testing was aimed at improving car restraints for the “forgotten age” of children. Many European countries require children to be in appropriate child restraints up to 12 years old or 150cm stature. Despite this, the use of CRS and particularly high-back boosters over the age of 8 years old is not widespread, leaving many children exposed to unnecessary risks. Euro NCAP’s opinion is that adequate side impact protection may be more achievable with a booster cushion and well-performing vehicle restraint systems than through the enforcement of high-back booster use in the real world. This, however, puts Euro NCAP at odds with ETC.

CONCLUSIONS

Safe transport of children is the joint responsibility of consumers, and child restraint and vehicle manufacturers. The approaches presented in this paper are complementary and both are needed to improve child safety in cars. Both ETC and Euro NCAP can look back at many years of testing which has had a real impact on the situation in the market place. They share many principles, viewpoints and objectives, but they also have different opinions on some points.

In general, both programs will continue to evolve and be updated according to relevant technical developments (such as the availability of new test methods, dummies, sensors and criteria), be guided by societal and market changes and stay aligned with type approval.

As mobility continues to grow and is radically transformed by digitisation, decarbonisation and automation, the opportunities to further improve safety must be seized. This is also true for the safety of children in transport. For instance, child presence detection technology that can sense infants left in cars, are entering the market: built into the CRS, built into the car, or as loose accessories. Many them come with a smartphone app. ETC is exploring if and how this can be implemented in the program, while Euro NCAP will include this technology in the 2022 COP protocol [18].

We can expect that, in the future, communication protocols will allow the CRS and the car to exchange information, such as crash direction and severity, that features built into the CRS can detect [19]. The effectiveness of such technology may also be considered in one or both programmes, as it becomes available.

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DEVELOPMENT OF A CERTIFICATION PROCEDURE FOR NUMERICAL PEDESTRIAN MODELS

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ABSTRACT

In the Euro NCAP testing of deployable pedestrian protection systems (i.e. active bonnets and airbags), head impact time (HIT), wrap around distance and bonnet deflection due to body loading are assessed by means of simulations with numerical pedestrian models. The aim of this study was to define requirements for numerical pedestrian models and simulation setups to ensure comparable performance of models and simulation results. These requirements were summarized in a certification procedure which focuses on the pedestrian's kinematics that are important for the Euro NCAP assessment. Twelve different institutions (academia and industry) applied a harmonised pedestrian simulation protocol, which was established within a previous study. Numerical pedestrian models in the stature of the 50th percentile male (all applicable for the assessment of deployable systems until 2017) were impacted with four differently shaped generic vehicle models at three different collision speeds according to the protocol. Trajectories, contact forces and HITs were evaluated. Finally, 18 full data sets including the 12 load cases were available covering different Human Body Models and Humanoid Multibody Models in four different FE codes. Reference values, corridors and tolerances for the certification procedure were derived, based on identified consistent results. Comparable behaviour was observed for the majority of pedestrian models. However, a small number of simulations showed clearly outlying behaviour in terms of HITs, trajectories and contact forces. The consistent models were within a range of +3.5% and -7% throughout all load cases. Corridors for the z- and x- trajectories as a function of time were developed for the head centre of gravity, T12 and the centre of acetabuli for each load case. Furthermore, corridors for the contact forces between pedestrian model and generic vehicle model were established. The developed certification procedure ensures that a specific pedestrian model within a specific environment, solver version and specific simulation settings gives comparable kinematic results relevant for the assessment of deployable systems. Inconsistent pedestrian models, incompatibilities with control settings and user errors can be identified and sorted out. The procedure was implemented in the Euro NCAP Technical Bulletin 24 and has been in force since January 2018.

INTRODUCTION

The Euro NCAP (European New Car Assessment Programme) assessment of deployable systems (i.e. active bonnets) represents the first application of Human Body Models within a consumer information safety rating. The timing and the impact location of the head are essential information for the assessment of deployable systems such as active pop-up bonnets. The system must detect the pedestrian and deploy rapidly enough before the head contacts the bonnet. Furthermore, evidence must be provided showing that the bonnet and the support structures are sufficiently stiff to ensure that the additional clearance has not already been significantly compromised due to the body load prior to the head impact.

These parameters cannot be assessed using the conventional subsystem impactors. Therefore, input from simulations is needed: A hybrid approach has been adopted by Euro NCAP for the assessment of deployable systems, which covers virtual simulations with pedestrian models, and physical tests with pedestrian subsystem impactors. The simulations with the pedestrian models are carried out to derive inputs for the subsequent physical tests with headform impactors. The virtual tests cover multiple collision speeds and pedestrian statures: Firstly, the head impact location (*WAD*) and Head Impact Time (*HIT*) for several pedestrian sizes are determined to assess whether the system can be fully deployed by the time of head impact for the most critical pedestrian stature. Secondly, the pedestrian size that is hardest for the sensor system to detect can be determined by means of performing simulations as an alternative to physical tests and to select appropriate test tools, which is in almost all cases the 6yo stature. Finally, the bonnet deflection due to the bonnet loading is derived from the simulations with pedestrian models to prove that the head protection is not compromised by a collapse of the bonnet. Based on the simulation results, physical tests are performed when the active bonnet is deployed, undeployed, or deploying. Conventional headform impactors are used, and the measured linear accelerations are applied to derive the Head Injury Criterion (*HIC*) values upon which the final scores are based. [1]

The virtual pedestrian simulations described above must be carried out at varying collision speeds with several sizes of the pedestrian models (6yo, 5th, 50th, 95th) but Euro NCAP does not specify the type of Human Body Model [1]. Ensuring comparability of simulation results for this application, however, is of great importance as differences between simulated HIT values and the total response times (TRT= sensing time + deployment time) of the active bonnets are often very close. This is shown in Figure 1, where results submitted to Euro NCAP are shown, which were used for the assessment of deployable systems. The HIT values of the simulations with different pedestrian statures are overlaid and compared with the TRT values. HIT values are only provided for the statures where head contact with the bonnet occurred, which is why there are fewer values for the 95^{th} model (green bars), than values representing the other statures. The 6yo model was not contacting the bonnet in only two of the 47 analysed dossiers. In six cases the TRT was higher than the TRT of the smallest pedestrian model that impacts the bonnet. The average relative positive deviation between the HIT of the smallest stature that was impacting the bonnet and the TRT was 15.6% and the median relative deviation was 11.7% (for the 41 results in which the HIT was ≤TRT). In five of the dossiers the HIT value of the 6yo model was even equal to the TRT.

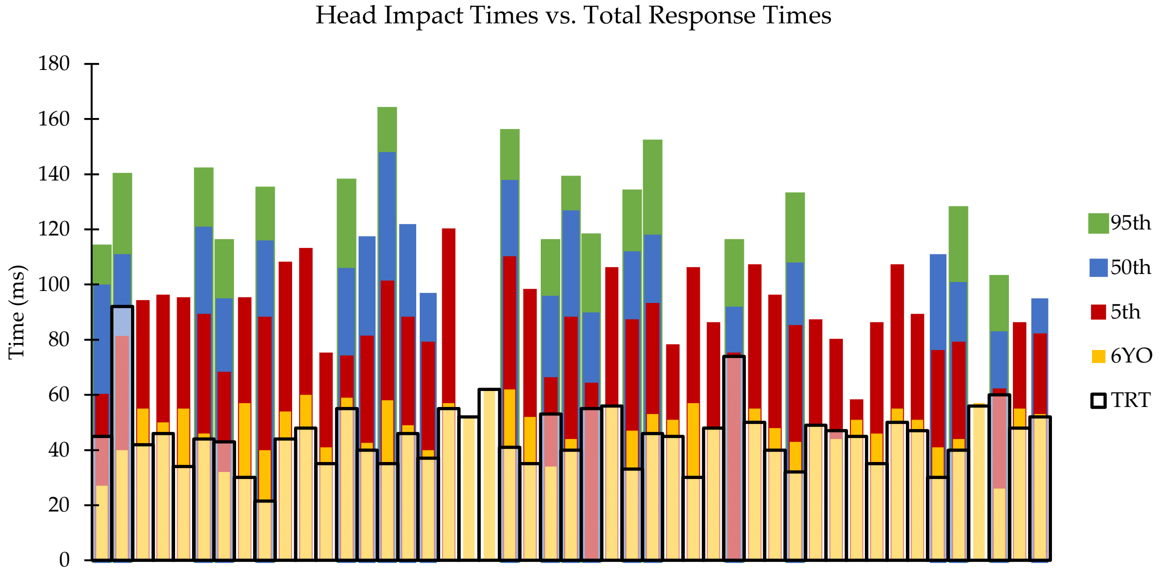


Figure 1: Head Impact Times of different pedestrian sizes overlaid and compared to Total Response Times of active bonnets based on results submitted to Euro NCAP from 2010-2018 (n=47).

Prior to 2018, all pedestrian models listed in Technical Bulletin 13 [2] could be applied for the virtual part of the assessment [1]. The list of models did not cover the effects of altering simulation settings and was difficult to maintain, because HBMs are continuously revised. Furthermore, the protocol did not include all details for the HBM simulations (e.g. open arm and torso posture, open contact settings), although these boundary conditions have been shown to have an effect in several studies [3–9].

As an alternative to a list of models, a certification procedure for virtual pedestrian models was established within the current study. The idea of the certification procedure is that simulations performed by a specific user with a specific HBM using a specific FE solver and specific control settings can be compared to a set of reference simulations. This will help to ensure comparability of the simulation results. For the final assessment simulations only the vehicle model is exchanged (using the detailed serial FE vehicle model to be assessed instead of the generic vehicle model), while anything else (solver, control settings, pedestrian model, contact settings) remains unchanged.

The aim of the study was to define corridors and tolerances for a certification procedure based on consistent reference results from state-of-the-art HBMs.

METHOD

Simulation setups

Generic vehicle (GV) models were applied as impact structures. The GV models were defined such that were easily transferrable to other codes and were thus applicable for comparison of HBMs in different codes (LS-

Dyna, VPS, Radioss and Abaqus). The model structure and geometry is explained in detail in [10]. Four different shapes of the models were established, representing the geometry of an FCR (family car), an MPV (Multipurpose Vehicle), an RDS (roadster) and an SUV (sport utility vehicle). The LS-DYNA version of the GV models was translated into the other FE codes by the FE code houses (ESI Group, Altair and Dassault Systèmes). The simulation protocol was developed with THUMS v4.02 and the simplified GHBMC pedestrian model in LS-DYNA and was published previously [10,11]. Twelve load cases were defined, in which the pedestrian is impacted with the four GV models at three different collision speeds (30, 40 and 50 km/h) in a specified reference posture [10] mimicking a natural walking position.

Analysed outputs

Sensors were implemented in the HBMs at selected reference points for the evaluation of trajectories:

- the head centre of gravity (HC)
- the centre (average of all nodal coordinates) of the vertebral body of C7 and T12
- the midpoint of the left and right centre of the acetabulum (AC)

A detailed description of the reference point sensor locations can be found in the Appendix (Table 2), allowing different users to position comparable sensor positioning in multiple HBMs. The sensors were connected with the structure using the keyword *CONSTRAINED_INTERPOLATE in LS-DYNA. In the other FE software packages, keywords with the same algorithm were identified and are provided in Table 3 in the Appendix.

For the evaluation of the trajectories, the x-displacement of the vehicle was subtracted from the x coordinates of the sensors (stationary vehicle view in local vehicle coordinate system) according to Figure 7. Contact forces and node histories were outputted every 0.1 ms. Unfiltered curves were used.

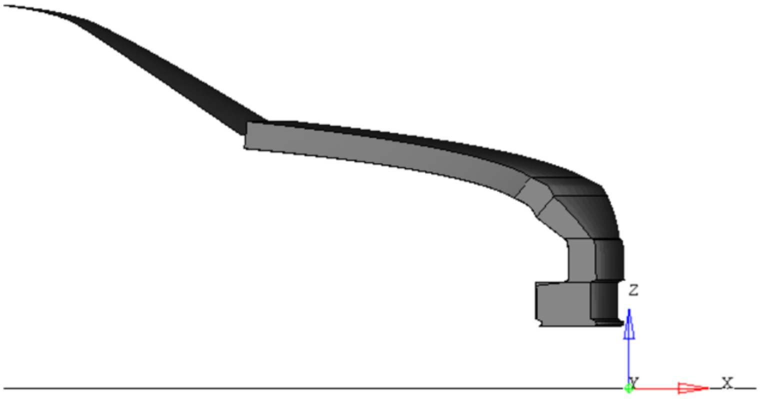


Figure 2: Coordinate system of the vehicle as applied in this study (x=0 at foremost point on vehicle front).

The kinematic assessment placed a focus on the head, as this is most relevant for the assessment of active bonnets.

The *HIT* was defined as the time from the first increase in the bumper contact force (*C*) until the first increase in the contact force between the head and vehicle (*H*), as shown in Figure 3 and described in Equation 1.

$$HIT\ [ms] = H - C \qquad \text{(Equation 1)}$$

The acceleration measured within the head CoG was also used to double-check the result, as shown in Figure 3. To determine *C,* only the contact between the lower extremities and bumper was considered (as this is also used as a trigger for active bonnets). A first contact between upper extremities and bumper was ignored.

The contact forces were separated by body region and contact surface. For the comparison between the models, the resultant total contact force between HBM and GV was used. The times of all contact forces were offset with the value C (time of first contact = 0).

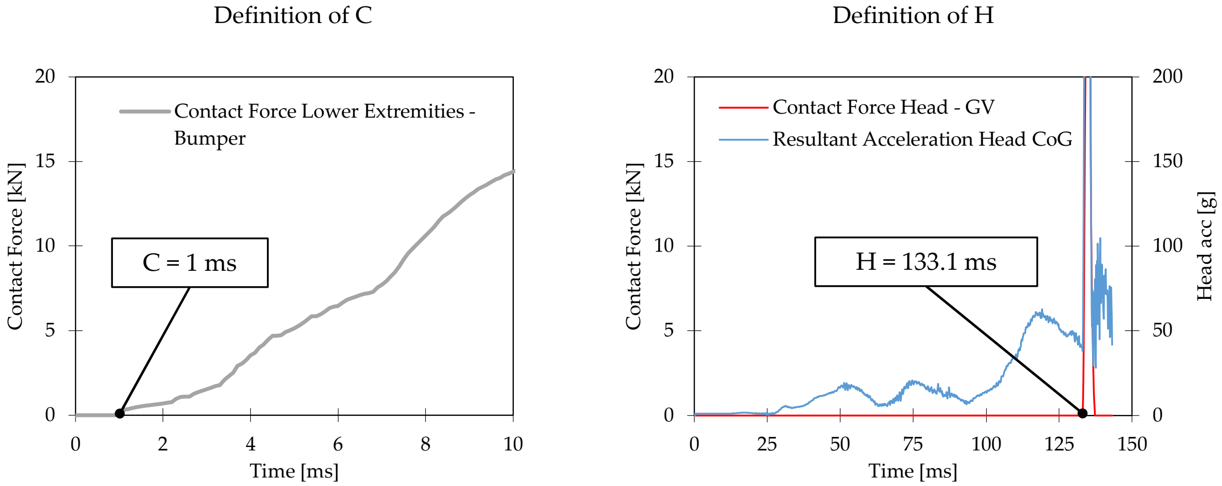


Figure 3: Example for the calculation of HIT based on H and C.

Dataset

A number of institutions from around the world run simulations according to the protocol [10] using the GV models and have provided their results. These are Audi AG, BMW Group, Daimler AG, ESI Group, HongIk University, Jaguar Land Rover, Honda R&D, Japan Automobile Manufacturers Association (JAMA) and Japan Automobile Research Institute (JARI), Nissan Motor Company, Siemens Industry Software and Services B.V. (formerly known as Tass International), Subaru Corporation and Wake Forest University. The results from the following pedestrian models (HBMs and multibody humanoid models) were included in the final dataset (random order):

- GHBMC simplified pedestrian model:
  - VPS version without fracture mode (two different institutions)
  - RADIOSS version without fracture mode
  - LS-DYNA with fracture mode (v1.4.5 and v1.4.3)
- THUMS:
  - THUMS v4.02 in LS-DYNA without fracture mode (two different institutions)
  - THUMS v4 in VPS without fracture mode
  - THUMS TUC in LS-DYNA without fracture mode
  - THUMS-D in LS-DYNA without fracture mode
  - THUMS v3 in Abaqus without fracture mode
- JAMA Pedestrian Model (HBM) in VPS with and without fracture mode
- Honda HBM in VPS without fracture mode
- Simcenter Madymo™ pedestrian models (multibody humanoid model) coupled with LS-DYNA (two different institutions)
- JLR humanoid FE model in LS-DYNA
- ESI PED 50 humanoid FE model in VPS

The results were anonymised and named as Model 01 to Model 18. All of the above listed models were included in the list of Euro NCAP TB013 and were, therefore, applicable for Euro NCAP assessment of deployable systems until December 2017.

The results from different models at different institutions and in different FE software packages were grouped into “consistent” and “inconsistent” results based on qualitative comparisons of the curves and the results of the statistical analyses.

Boxplots were used to identify outliers and to compare the HITs. Outliers were defined as points beyond the 1.5 interquartile ranges ($IQR = Q3 - Q1$) from the median value (shown as a whisker in the diagrams). Reference values and tolerances for head impact times were derived.

Corridors were derived for trajectories for the locations of HC, T12 and AC based on the consistent results. The median, minimum and maximum values for each coordinate were derived from all consistent results every 0.1 ms.

Additionally, corridors for the total resultant contact force between HBM and GV were defined based on the minimum and maximum value of the consistent results (again every 0.1 ms).

RESULTS

Eighteen different dossiers of results were available for the subsequent analysis, again using the names Model 01 to Model 18. In the case of Model 5, no results of the impacts with 30 km/h were provided. The dossier was complete for all other models and included all twelve load cases. In the first step, outliers were identified and removed from the dataset. Corridors for the trajectories, displacements and contact forces were specified based on consistent results. Furthermore, reference values and tolerances for *HIT*s were defined for the final certification procedure.

Head Impact Time

The head impact times resulting from the eighteen different pedestrian simulations with varying pedestrian models in four different codes are shown in Figure 4. Boxplots were created to identify outliers in the datasets. The boxes show the 1st quartile (*Q1*), median value and 3rd quartile (*Q3*). The whiskers represent the highest or lowest value within the 1.5 *IQR*. The cross indicates the mean value for each load case. As the distributions were not symmetric, the median values together with quartiles were found to be more useful than the mean values with standard deviation.

Six outlying results were identified and are shown as circles in the figure: Results from Pedestrian Models 2, 5, 6, 11, 12 and 15 did not fall within the 1.5 *IQR* for at least one load case.

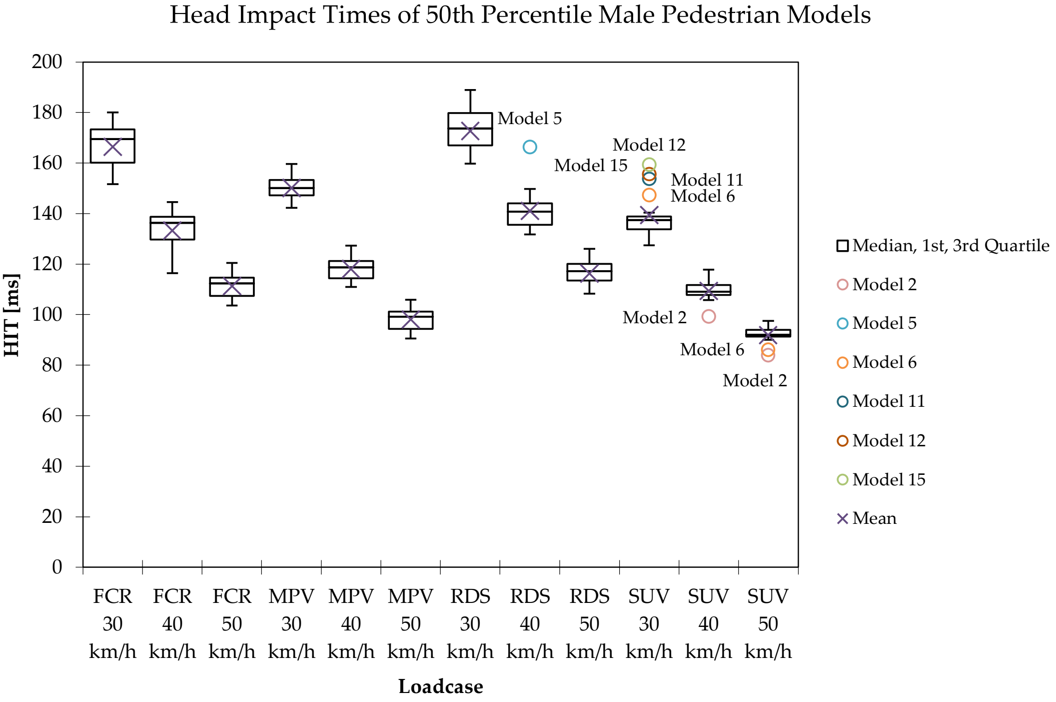


Figure 4: Boxplots of HITs from eighteen different pedestrian simulations for impacts with FCR, MPV, RDS and SUV at 30, 40 and 50 km/h with outliers marked with circles.

In the next step, the outliers were excluded from the dataset that was used to define the tolerances and corridors. The median value from the remaining data was calculated as a reference value. The relative deviation of each result from the reference value per load case was calculated as a percentage and plotted in Figure 5. All datasets with outlying behaviour were marked as unfilled circles and the remaining, consistent datasets that were also used to derive the median / reference value are shown as filled circles. A maximum span of 24% variation of *HIT* compared to the reference value in one loadcase (SUV 30 km/h) was observed in the dataset for all the results provided. Pedestrian Model 2 showed smaller *HIT*s than the consistent models in most of the load cases. For the other outlier models, no clear trend could be detected. While they tended to have smaller *HIT*s for family cars, higher *HIT*s were observed for the SUV impacts at 30 and 40 km/h.

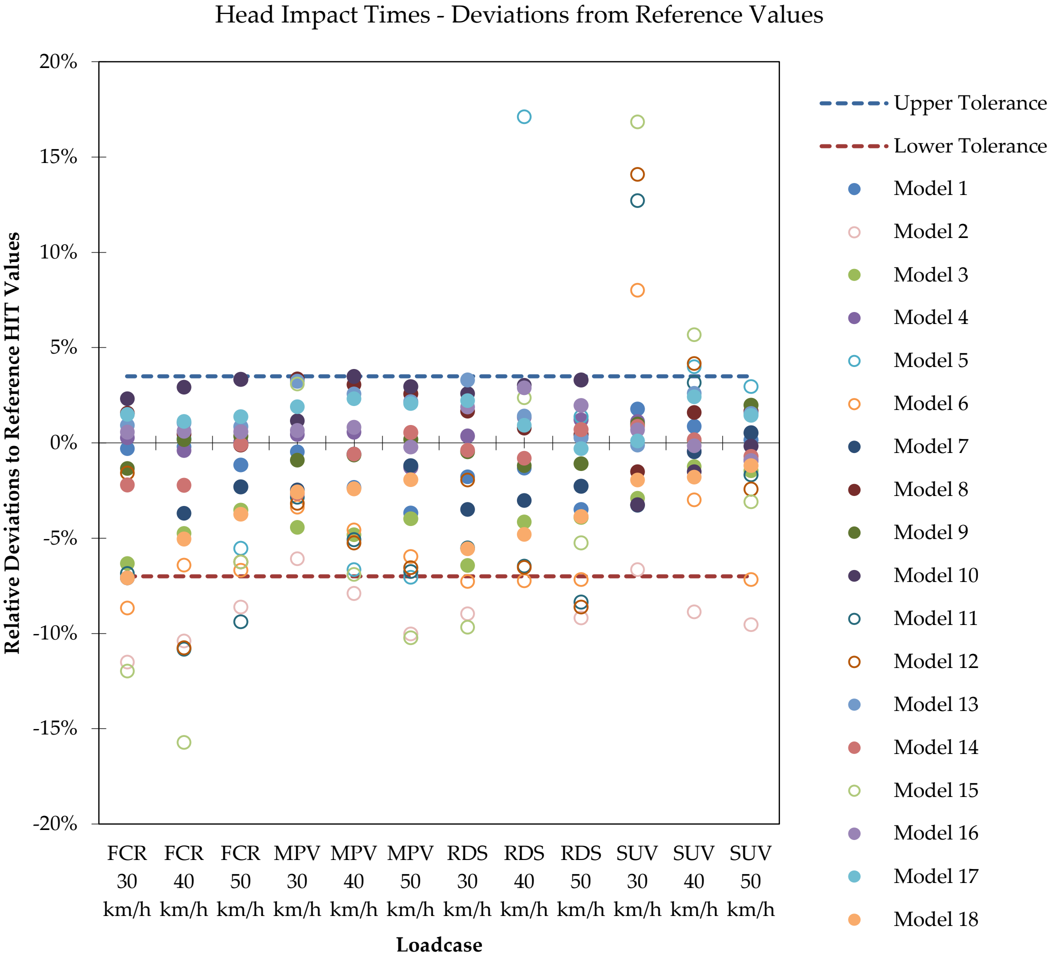


Figure 5: Deviation from reference HIT values of the eighteen different datasets in percent for all twelve load cases (FCR, MPV, SUV, RDS at 30, 40 and 50 km/h).

The maximum and minimum relative deviations within the consistent datasets from the reference value were +3.5% (Model 10 for impact with MPV at 40 km/h) and -7% (Model 18 for impact with FCR at 30 km/h), respectively. These values were chosen as upper and lower allowed tolerance values for the current certification procedure [12]. The reference values together with the derived upper and lower boundaries for the certification procedure are summarised in Table 1.

Table 1.
Reference HIT values and upper and lower boundaries for the certification procedure.

HIT [ms]	**FCR**			**MPV**			**RDS**			**SUV**		
v [km/h]	30	40	50	30	40	50	30	40	50	30	40	50
Reference value	172.3	138.1	114.3	151.5	120.4	100.8	176.9	142.1	119.3	136.5	109.0	92.9
Maximum value (+3.5%)	178.4	143.0	118.4	156.9	124.7	104.4	183.1	147.1	123.5	141.3	112.9	96.2
Minimum value (-7%)	160.2	128.4	106.2	140.8	111.9	93.7	164.5	132.1	110.9	126.9	101.3	86.3

Trajectories

When analysing the trajectories, it was observed that Models 2 and 15 were also outliers in terms of the initial location of the head CoG. They are shown in red in Figure 16 and Figure 6. The initial posture of the head CoG was significantly lower than that of the other models (1635 mm and 1638 mm, respectively, while the median value was 1680 mm and 1.5 IQR was 10 mm). They were even beyond the 95% interval of the mean value ± 2 times the standard deviation (1644-1714 mm).

The head CoG of Model 14 was initially located at 1714 mm and, therefore, higher than the median value ±1.5 IQR, but fell within the 95% interval. It was maintained in the data sample, since it showed no outlying behaviour in terms of its *HIT*, i.

The minimum and maximum values for each time step were derived in the x and z-directions $(x_{min/max}\ and\ z_{min/max})$. All models that displayed outlying behaviour in terms of their *HIT*s were excluded prior to creating the corridor. The corridors shown in Figure 6 are exemplary for the 40 km/h impact with the FCR and were derived by connecting the coordinates $[x_{min}(t_n) \quad z_{min}(t_n)]$ for the ascending trajectories (HC, T12) and $[x_{min}(t_n) \quad z_{max}(t_n)]$ for the descending trajectories (AC), as shown in Figure 7. The thick black line in Figure 6 shows the corresponding corridor that was created. Each colour represents the results of one pedestrian model.

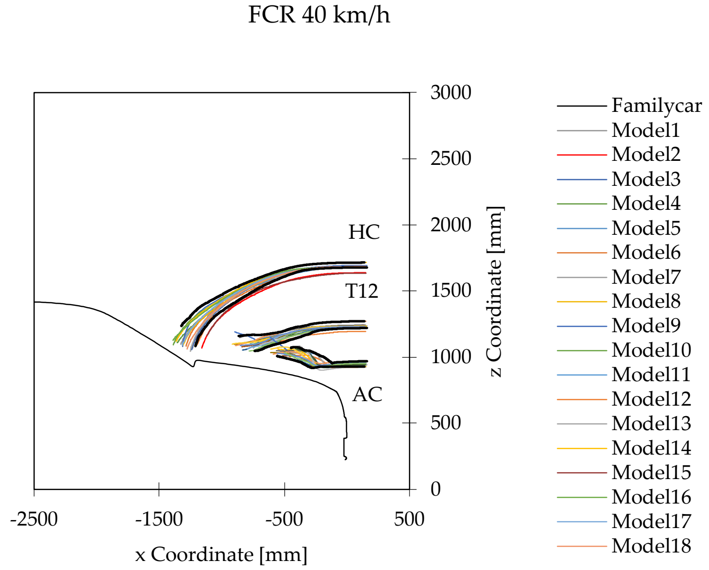


Figure 6: Corridors (black line) for trajectories for z as a function of the x trajectory relative to the vehicle coordinate system for the FCR impact at 40 km/h.

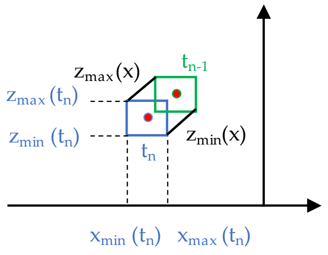
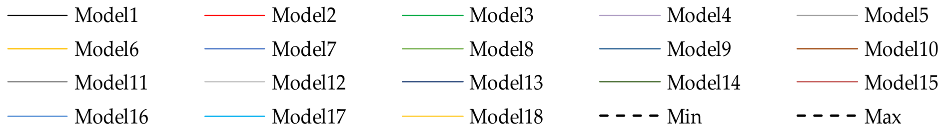


Figure 7: Relationship between time-dependent and x-trajectory-dependent corridors.

As timing is essential for the assessment of the deployable systems, a time dependent approach was finally chosen. This means the coordinate of the analysed reference point (shown as a red point in Figure 7) must lie within a box extending from x_{min} to x_{max} and z_{min} to z_{max} (shown as blue and green boxes in Figure 7 for two different time steps) at each time step. The resulting corridors for z and x as a function of time are shown in Figure 8-Figure 13 as black dashed lines.



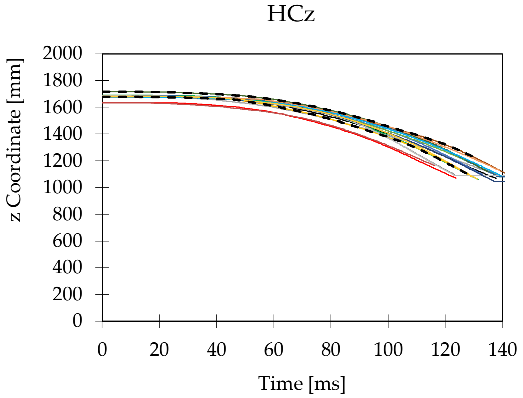


Figure 8: Corridor for the z trajectory as a function of time (black dashed line) for Head CoG for FCR 40 km/h load case.

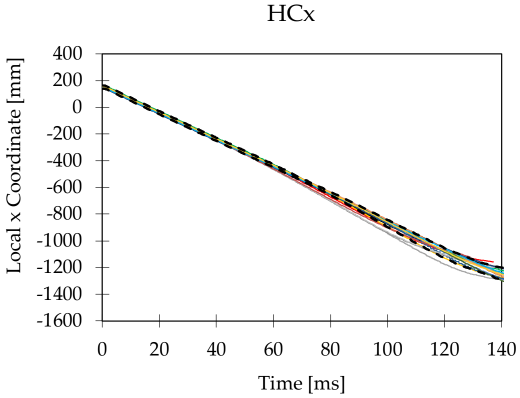


Figure 9: Corridor for the x trajectory as a function of time (black dashed line) for Head CoG for FCR 40 km/h load case.

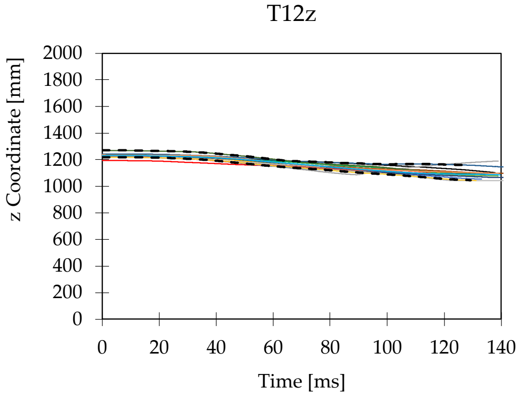


Figure 10: Corridor for the z trajectory as a function of time (black dashed line) for T12 for FCR 40 km/h load case.

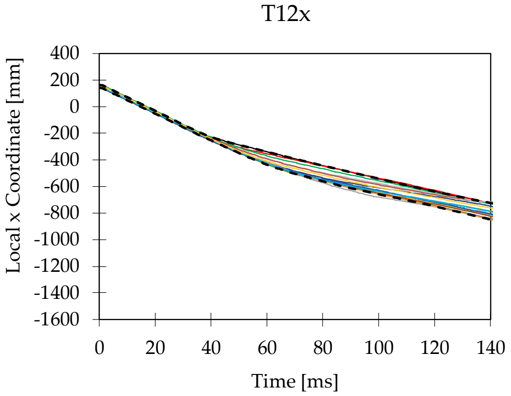


Figure 11: Corridor for the x trajectory as a function of time (black dashed line) for T12 for FCR 40 km/h load case.

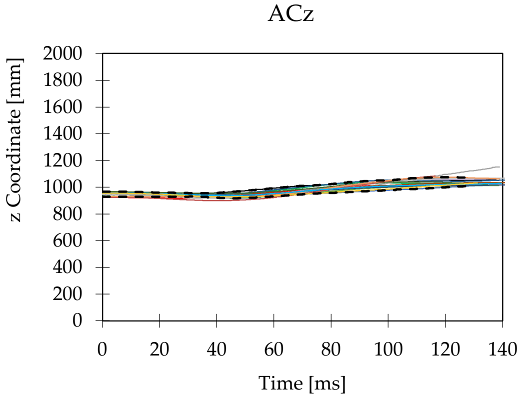


Figure 12: Corridor for the z trajectory as a function of time (black dashed line) for centre of acetabuli for FCR 40 km/h load case.

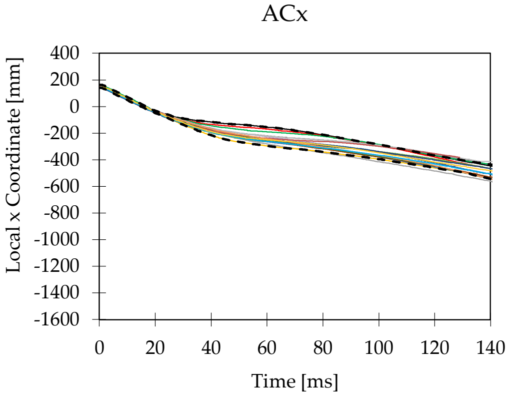


Figure 13: Corridor for the x trajectory as a function of time (black dashed line) for centre of acetabuli for FCR 40 km/h load case.

As shown in Figure 8, Models 11 and 12 (already defined as outliers because of their *HIT*s – shown in grey) fell outside the z corridor towards the end of the simulation. The responses of the other fourteen pedestrian models remained inside the corridors. The corridors for all the load cases can be found in the Appendix.

Contact Forces

Figure 14 shows the resultant total contact force (unfiltered) observed between the pedestrian and GV using the varying HBMs and varying codes, for the 40 km/h impact with the generic FCR model. At around 130 ms the head is impacting the rigid windshield, which is why the forces are increasing drastically. All results for which *HIT*s or trajectories showed outlying *HIT* behaviour are shown in grey. Additionally, the red and orange lines (Models 1 and 3) were also removed, as they showed significantly higher first peaks compared to those in the other models. The corridors, shown as black dashed lines, represent the minimum and maximum values of the contact forces of the remaining consistent models as derived at each time step.

The final corridors for all load cases are shown in the Appendix. Code-specific issues were identified when analysing the contact forces, which is why the contact force corridors are used for monitoring purposes only at the current stage.

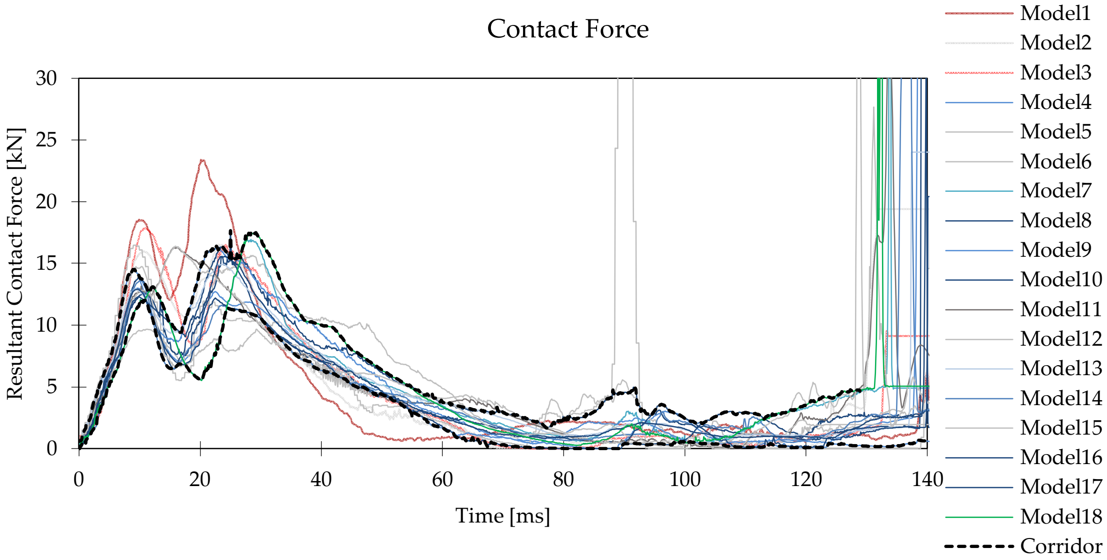


Figure 14: Total resultant contact forces between vehicle and pedestrian models for all submitted results and the derived corridors for a 40 km/h impact with an FCR.

DISCUSSION

Analysed output

A cross-check with the head acceleration in the resultant and global z-directions was performed to see if the time of the head impact had been determined correctly. Whenever the maximum resultant head acceleration was observed before the derived time *H* of head contact, a manual check was performed by examining the animated results. In some cases, this discrepancy was caused by the fact that a direct contact between the head and GV was avoided, as the arm was located between head and GV, leading to high accelerations in the head, but no measured contact force between the head and GV. In these cases, the applied definition led either to no identifiable, or a very high *HIT*.

Three approaches could be applied to deal with this issue:

1. The time *H* could be defined as the time when the head contacts the arms and at the same time the arms contact the vehicle
2. The time *H* could be defined as the time of maximum head acceleration
3. The contact between arms and head could be disabled in such cases.

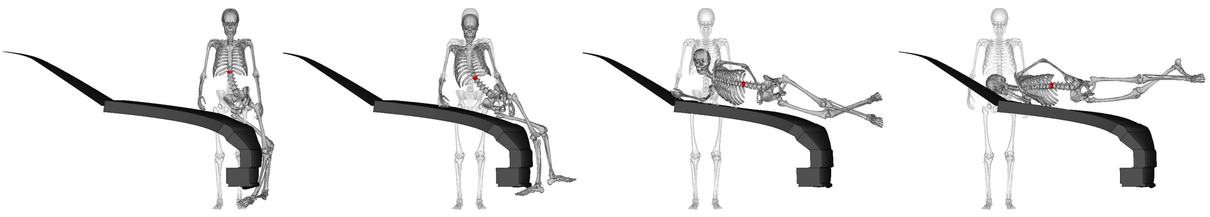
Approach 1 leads to significantly lower *HIT*s compared to those obtained in simulations with no contact between arms and head and, therefore, leads to less comparable results. Approach 2 can lead to misleading results, as multiple peaks in the head accelerations were observed in some simulations. When the head of the HBM contacts the shoulder, this can lead to even higher acceleration than if it contacts the bonnet. For these reasons, approach 3 was chosen as it allowed an automatic analysis of *HIT* to be performed and the most readily comparable results to be obtained.

To cover the body kinematics that were relevant for the chosen assessment focus, the trajectories for the head CoG (HC), centre of T12 and the centre of *acetabuli* (AC) were considered as the final reference points and corridors were defined for these: The location of the head is obviously important for the assessment of deployable system because the wrap-around distance and HIT are important outputs for the assessment simulations. AC and T12 enable an analysis of the hip and the torso kinematics, which are important for the evaluation of the deflection due to the body load and for avoiding implausible full-body kinematics. The reference point AC tends to be close to the CoG of the full-body, and the CoG of the torso is located between AC and T12.

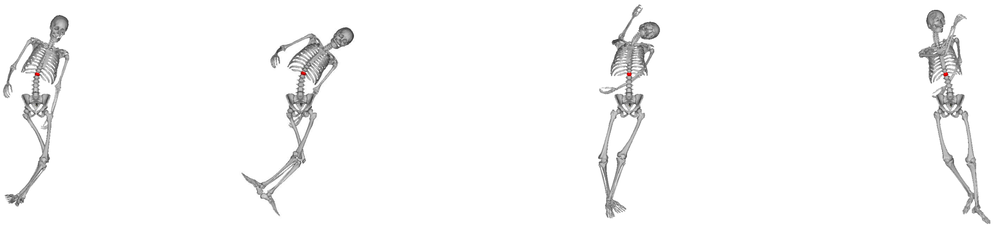
Furthermore, T12 and AC together were shown to be indicators that could effectively be used to identify the time when the curvature of the spine started to change its direction. The spine kinematics could be separated into two phases as shown in Figure 15. In the first phase, the pelvis moved away from the head and the upper torso as it was accelerated by the vehicle impact, while the upper torso and head remained in place due to their inertia. The spine posture at 66 ms showed the maximum spine curvature for this load case (FCR impact at 40 km/h) as the pedestrian wrapped around the vehicle. The head and upper torso then were pulled downwards and the spine was straightened, before its curvature changed into the other direction prior to the head impact at 140 ms. This is clearly visible when examining the figures that had fixed pelvises on the bottom of Figure 15 showing the skeleton of THUMS v4.02 in simulations with the GV FCR model in LS-DYNA: In phase 1, T12 is located on the left side of AC, while it is located on the right side in phase 2. The observed kinematics are in accordance with movement patterns seen in PMHS tests [13].

Phase 1 **Phase 2** **Head Impact**

Full-body kinematics (initial position in the background) in the global coordinate system.



Spine kinematics relative to fixed pelvis coordinate system.



42 ms 66ms 118 ms 140 ms

Figure 15: Kinematics of the spine for an impact with the generic FCR model at 40 km/h relative to the global and a local pelvis coordinate system (T12 shown in red).

The trajectories of the lower extremities were not relevant for the assessment of active bonnets and, therefore, were not included.

Alternative corridor definitions

To define the corridors for the certification procedure, several approaches were taken into account. As a first approach, the method described in the SAE norm J2868 [14] was applied, defining the corridor as a percentage of the path length based median reference trajectories. In this approach, the path length at each time step is derived from the median x and z coordinates for each reference point as a first step. A tolerance of +10% and -5% of the path length is added to the median trajectory, resulting in the corridors shown in Figure 16. As the corridor for the head trajectory was much wider than the spread observed in the analysed data, the method was rejected.

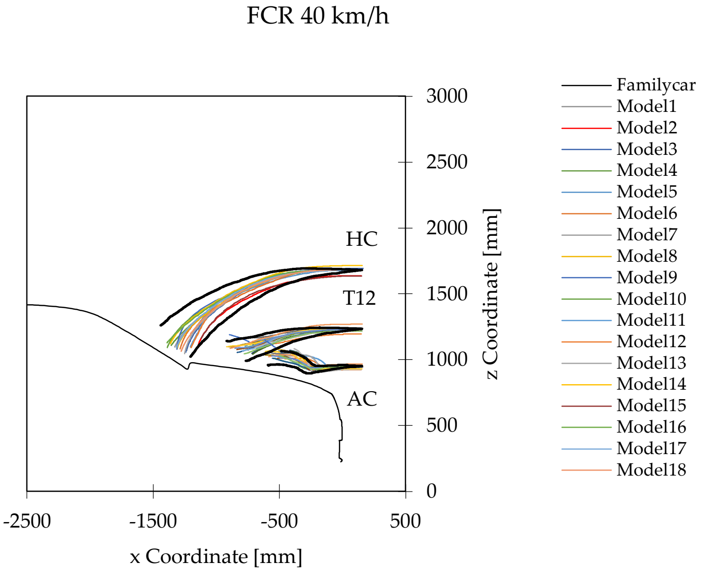


Figure 16: Corridors derived with SAE J2868 approach based on path length for z as a function of the x trajectory relative to the vehicle coordinate system for the FCR impact at 40 km/h.

The corridors introduced in the current paper are based on minimum and maximum values at each timestep. After receiving the first ten certification dossiers, it was realised that even the models used to create the corridors can fall out of the corridor for a short duration (a few milliseconds) and for a few millimetres. Numeric effects can lead to such small deviations, which can be crucial for models that are defining the upper and lower boundary of the corridors. Therefore, an appropriate tolerance was defined for the introductory period. The reference points are allowed to have a maximum deviation of 50 mm to the reference corridors in x- and z-direction. This reference was chosen, as it represents the half the size of the grid used for the head impactor tests. However, at the beginning of the corridor the differences between the models tend to be very small and therefore the additional tolerance tends to be higher in that time period than the maximum differences observed in the simulations.

As a next step, new corridors will be established that are based on another alternative method to avoid this issue, where the mean location at each time step and a corridor based on standard deviations (SD) are derived.

The locations of the reference points in the local vehicle coordinate system (x_i and z_i summarized as c_i) are paired with the time (t_i) as sequences.

$$(t_i, c_i) \text{ for } i = 1, \dots, n. \qquad \text{(Equation 2)}$$

Since multiple datasets are available, there are m sequences of measured values

$$(t_i^r, c_i^r) \text{ for } r = 1, \dots, m \text{ and } i = 1, \dots n_r \qquad \text{(Equation 3)}$$

where a mean of c over r is of interest at each t_i. Subsequently, only sequences are considered which have the same time resolution, but they might stop at different lengths, so n_r can be different for each r. To simplify notation, it is further assumed that the sequences are ordered by their length i.e. $n_1 \geq n_2 \geq \cdots \geq n_m$. The number of sequences that have values for an index i will be denoted as m_i. So m_i equals m for $i \leq n_m$ but it might be smaller than m for $i > n_m$. Let $\bar{n}$ be the longest sequence length for which all sequences have values i.e. $m_i = m$ for $i \leq \bar{n}$ and $m_i < m$ for $i > \bar{n}$. If all sequences have the same length, the mean can be calculated by simply taking the mean over all y-values for each x-value, that is

$$c_i^{mean} = \frac{1}{m}\sum_{r=1}^{m} c_i^r. \qquad \text{(Equation 4)}$$

If the sequences have different lengths, this approach can be modified to

$$c_i^{mean} = \frac{1}{m_i}\sum_{r=1}^{m_i} c_i^r. \qquad \text{(Equation 5)}$$

However, this will lead to “jumps” when a sequence ends. In the following, a method will be outlined to calculate a mean that avoids these “jumps”. As long as there is data for all sequences, the usual mean will be used i.e.

$$c_i^{mean} = \frac{1}{m}\sum_{r=1}^{m} c_i^r \text{ for } i \leq \bar{n}. \qquad \text{(Equation 6)}$$

To calculate the mean for $i > \bar{n}$, a mean of the changes of the c is used. Let $\Delta c_i^r = c_{i+1}^r - c_i^r$ be the difference between two consecutive c in the r^{th} sequence. The mean of these differences can be calculated by a similar formula as the mean of c, as

$$\Delta c_i^{mean} = \frac{1}{m_{i+1}}\sum_{r=1}^{m_{i+1}} \Delta c_i^r. \qquad \text{(Equation 7)}$$

To calculate the mean for $i > \bar{n}$ the previous mean value is updated with this mean difference i.e.

$$c_i^{mean} = c_{i-1}^{mean} + \Delta c_{i-1}^{mean} \text{ for } i > \bar{n}. \qquad \text{(Equation 8)}$$

Casually speaking, the mean moves in the direction of the mean slope. If all sequences have the same length, this approach would lead to the ordinary mean even if $\bar{n}$ would be artificially set to 1.

The upper and lower boundaries of the corridors are then defined at each time step as:

$$c_i^{corridor} = c_i^{mean} \mp 2 * SD_i \qquad \text{(Equation 9)}$$

If $i > \bar{n}$, SD_i is no longer updated and is set to $SD_{\bar{n}}$. The corridors according to this new method (SD based) are compared to the corridors introduced in this paper (Min/Max based corridors) in Figure 17. The advantage of the SD based method is also that the whole dataset can be used and outliers do not have to be sorted out necessarily to define the corridor (however, they will affect the standard deviation). The grey area in the figure shows the additional 50 mm tolerance that is allowed in the current version of technical bulletin. The SD-based corridor lay between this additional tolerance (grey shaded area) and the min/max based corridors and would therefore appear to be a good solution to solve the issues described above. If a higher tolerance is needed for an introduction period, the corridor width can be increased to $\mp 3 * SD$.

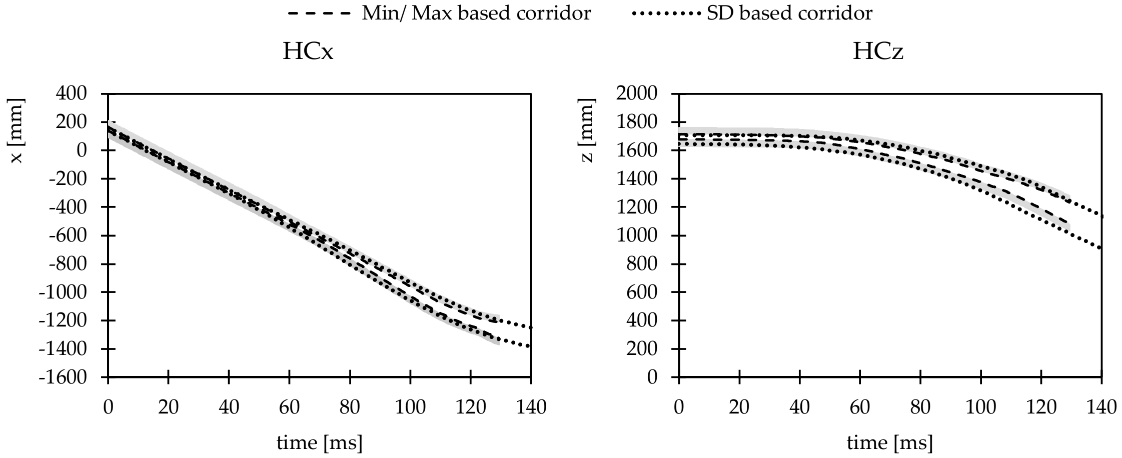


Figure 17: Comparison of time dependent corridors for HCx and HCz.

Comparability of results from HBM simulations

Although GHBMC PS and THUMS AM50 pedestrian models are validated using differing PMHS tests and do not have the exact same anthropometry, the kinematic responses seen were very similar. This was not true for some of the other pedestrian models. It was possible to identify outliers with inconsistent behaviour compared to the majority of results, and these will have to be revised to pass the certification.

Models that showed outlying behaviour for *HIT* also showed outlying behaviour for the trajectories, indicating that the chosen approach, which began with the identification of outliers based on *HIT*s, was appropriate. Two additional outliers were identified for the contact forces that showed comparable behaviour to the other results in the previous analyses. When examining the details, it was observed that discrepancies seem to come from specific output definitions of the contact forces in one FE software package. In the current certification procedure described in TB024 [12] the contact forces are only monitored, which means that the model response does not have to fall within the corridors. The attempt should be made, however, to harmonise the contact force outputs more, with the intention of being able to add this as an additional requirement in the future.

The presented certification procedure does not replace the validation of the HBM in terms of biofidelity. The certification proceeds the validation and allows an HBM in a specific environment to be used as a “virtual test device” for a specific assessment focus (in this case, the kinematic-based assessment of deployable systems). When performing any revisions of the Human Body Models, validations also have to be repeated. While the HBM has to be morphed to the anthropometry of the PMHS to perform a proper validation, reference anthropometries are needed for assessment purposes.

Certification procedures are important prerequisites for virtual testing, as they enable users to determine whether the response of a specific virtual test device in a specific environment answers a specific question and provides a comparable response. Within the certification procedure the response of the model is compared to reference simulations using the harmonized setup, target posture and harmonized anthropometry that should be also used for the final assessment simulations.

The certification procedure has been developed to provide evidence that the pedestrian model leads to comparable results within specified tolerance levels when it is applied in a harmonised setup (this is very similar to the setup that is used for the subsequent assessment). This is required to ensure that the variations in the results fall within an acceptable range. An alternative approach could also be taken to solve this issue: A virtual testing lab performs assessment simulations with the same pedestrian model in the same code for all kinds of cars. Still, once more than one test lab is performing the simulations, or more than one code is used, comparability would be unknown without a certification procedure.

The developed procedure allows users and evaluators to identify user errors when setting up the simulations and to find compatibility problems with FE solver versions. Furthermore, the certification can be used to check the sensitivity of the HBM when control settings have to be changed to comply with the full FE vehicles. The certification procedure can help to increase awareness of the fact that small changes can imply significant effects on the HBM simulation results and that precautions are needed as a result. It can be also used by HBM developers to check the robustness of their models.

The introduced certification procedure is only applicable to kinematic-based assessments. The comparability of injury metrics, and especially strain-based injury metrics, is not addressed. First of all, the kinematics and validations have to be harmonised. Once this has been achieved, similar methods could be applied to compare other metrics for varying models with different setups and codes.

The corridors and tolerances were defined using current state-of-the-art HBMs. No active pedestrian models were covered. The corridors and tolerances are based on biofidelic models, but should not be understood as biofidelity corridors. The corridors will need to be revised when significant changes in the state of the art of HBMs occur and biofidelity significantly improves compared to the current status (e.g. due to newly available test data).

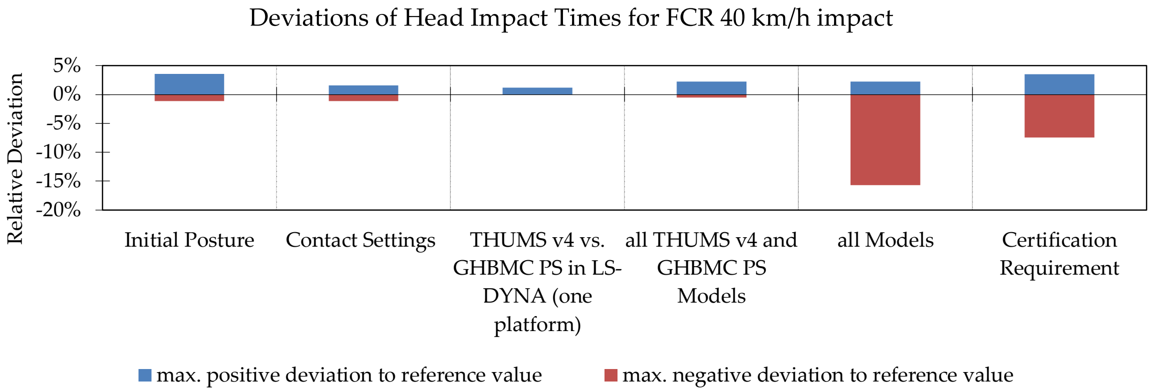


Figure 18 shows the deviations among the *HIT* resulting from different variations for one exemplary load case, the family car impact at 40 km/h, as this is the only load case where results for all variations were available: Due to the harmonised simulation protocol that was introduced in [10], it was possible to narrow down the differences between two models in one FE code and on one platform in terms of *HIT* from 4.7% to 1.2% for this load case. A total variation of 2.75% was observed from the results received with the two models THUMS v4 and GHBMC PS when including the external simulations performed in different codes by different institution.

Without a certification procedure, the models that were listed within TB013 were showing a variation of up to 18% within the FCR 40 km/h load case. Using the current version of the certification procedure results in a decrease in these differences by allowing a maximum of 10.5% variation.

Asymmetric tolerances for the HIT values were defined: A greater amount of negative deviation was accepted, because it represents the worst case for the assessment of the deployable system, while a too high *HIT* was unacceptable. The aim for the future should be to find a way of narrowing down the corridors in when harmonisation in the HBMs is progressing.

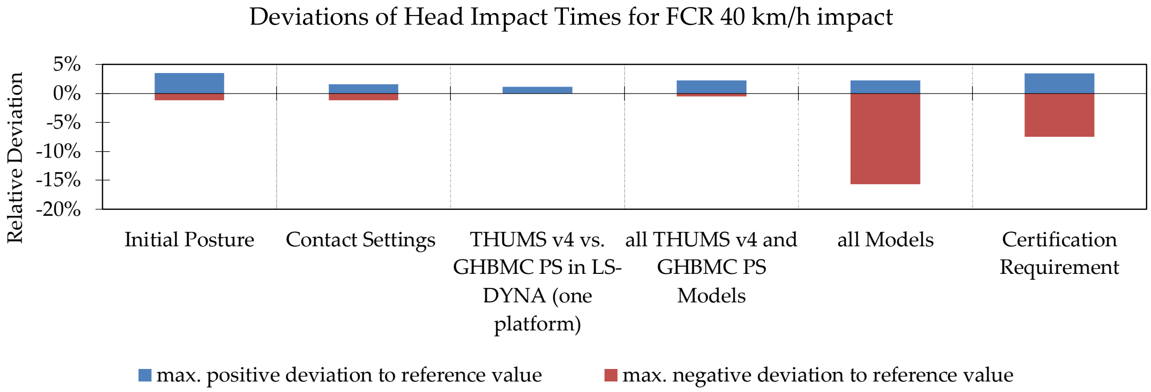


Figure 18: Relative deviations of HITs to reference HIT (138.1 ms) for the 40 km/h impact with generic FCR models.

The benefit of the certification procedure becomes even more obvious when examining the maximum differences observed throughout all load cases and all eighteen sets of analysed results. As shown in Figure 19, the sum of the absolute maximum deviations observed throughout all simulations made up a total of 33% (maximum of 24% within one load case). Due to the certification requirements, this is more than halved to a maximum of 10.5%. The critical positive deviation compared to the reference value, which led to higher *HIT*s, decreased from 17% to 3.5%. The results of the THUMS and GHBMC PS models – in all codes – did not need the full tolerance. Their results fell within a 6.5% range throughout all load cases.

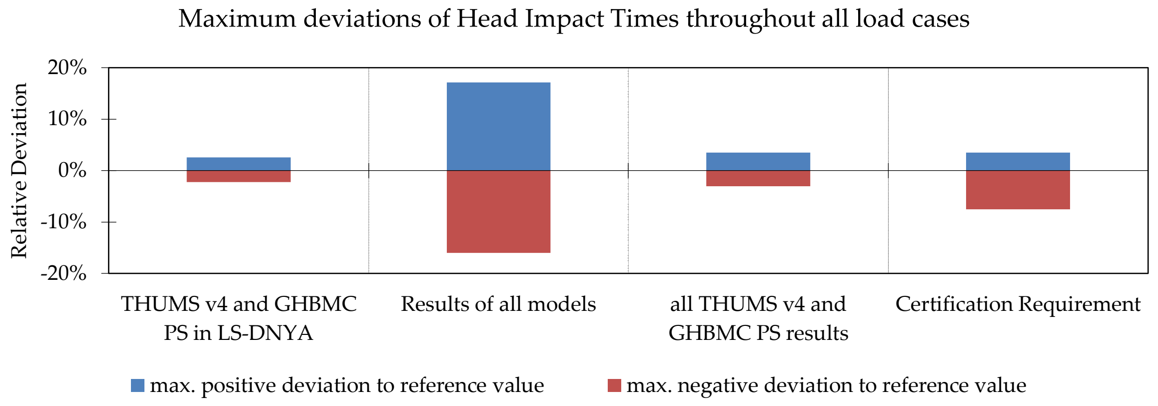


Figure 19: Relative deviations of HITs to reference HITs throughout all twelve load cases.

Outlook

As the 6yo child tends to be the most critical size when it comes to the evaluation of HIT, the response of those models was analysed as a next step. Some additional challenges for the child models were identified compared to the adult models: No full-scale PMHS tests are available with children. Furthermore, there are different kinds of child models available. While the adult models tend to differ only in terms of geometry, there are child models available that have been developed from scratch, such as the PIPER models [15], or some child models that belong to a family, but have been significantly adapted (e.g. material models), to better replicate a child, such as the GHBMC child model [16]. Another challenge is that the anthropometries among the child models differ more than the AM50 models.

The results of simulations with different child models have again been collected, to address those challenges by aiming to establish a second set of reference corridors for the pedestrian models in the size of the 6yo.

The work is still in progress, which is why the results are not included in the current paper. In contrast to the AM50 models, no clear outliers were identified. The preliminary results based on different GHBMC models, THUMS models, PIPER models and one Simcenter Madymo™ model are shown in Figure 20. Summarising all twelve load cases, the maximum spread of HIT values was -12% and +10% and the average spread -7.2% and +6.7% to the mean value derived for each load case, with the same methodology as for the AM50 model. The aim for the future should be to find a way of narrowing down these spreads.

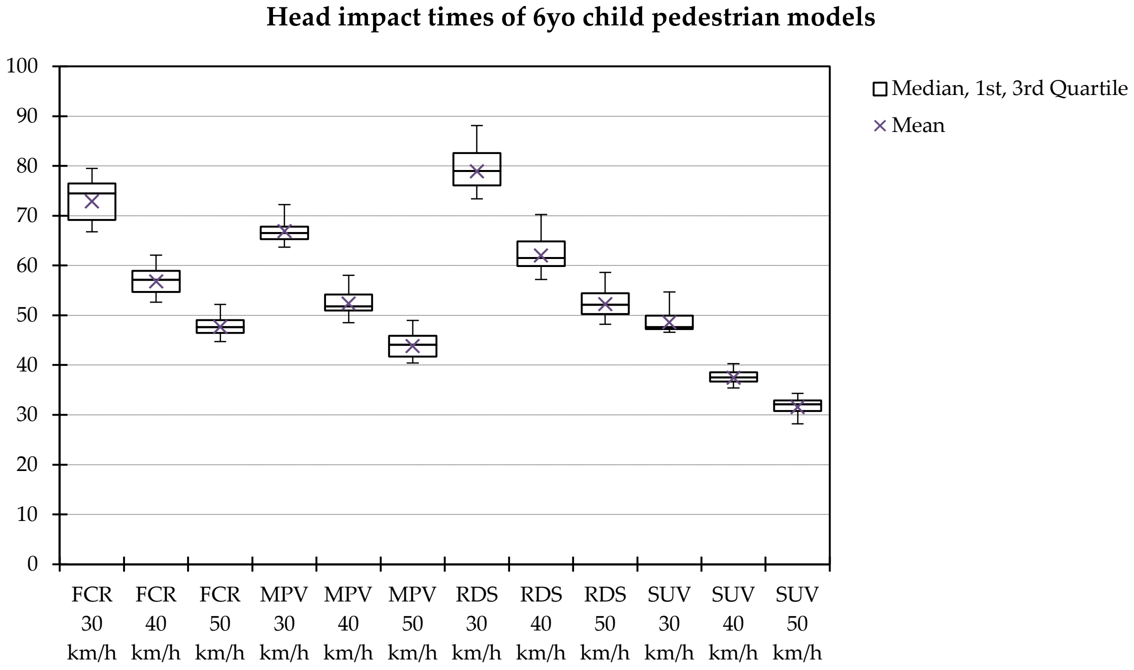


Figure 20: Preliminary HIT values for simulations with 6yo child pedestrian models shown as boxplots.

CONCLUSION

The paper describes the first certification procedure that enables an objective standardised comparison of the kinematic response of various numerical pedestrian models in multiple codes. The procedure was adopted by Euro NCAP and published as Technical Bulletin 024 in January 2018.

When eighteen different results for the twelve reference load cases – performed by different institutions with different HBMs in different FE software packages – were obtained according to the protocol, outliers were identified. The relative amount of deviation among the kinematic-based assessment results was drastically reduced when these were eliminated.

The newly developed certification procedure for HBMs limits the amount of variation allowed for the simulations in the reference load cases to the amount of variation that was observed within the consistent reference simulations (without outliers). The comparability of kinematic-based assessment was, therefore, drastically improved. While, for example, the head impact times in the initial data set varied by up to 24%, the procedure limits the variation to a maximum of 10.5%. This means that the relative deviation of results was more than halved for this output, which is essential for the Euro NCAP assessment of deployable systems.

Certification procedures for numerical models are an important prerequisite to enable virtual testing with numeric pedestrian models for the assessment of safety features. The developed certification procedure provides confirmation that a specific pedestrian model within a specific environment, solver version and specific simulation settings leads to comparable kinematic results relevant for the assessment of deployable systems. Inconsistent pedestrian models, incompatibilities with control settings and user errors can be identified and addressed.

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APPENDIX

Table 2.
Reference Points

Abbreviation	Long Name	Definition
HC	Head centre of gravity	CoG of all parts of skull, scalp, face, brain, intracranial space, scalp) connected to all nodes of inner cranium (at least 100 nodes)
T12	Centre of twelfth thoracic vertebrae	Centre* of all nodes of vertebral body (as defined in Figure 21) T12; connected to all nodes of vertebral body of T12
ACr	Centre of the right acetabulum	Centre* of all nodes within the concave surface of the right acetabulum as shown in Figure 22, connected with all nodes inside. The sharp edge where the bone changes curvature is selected as boundary, and all nodes inside are picked
ACl	Centre of the left acetabulum	As ACr, but for the right acetabulum
AC	midpoint of the right and left acetabulum centres	The midpoint of the left and right acetabulum centres (ACr and ACl) connected to all nodes of the right and left acetabulum.

* Centre always refers to the node with the averaged coordinates of the nodes that were selected to derive the centre as described in Equation (10).

$$x_c = \sum_{i=1}^{n} \frac{x_i}{n} \qquad y_c = \sum_{i=1}^{n} \frac{y_i}{n} \qquad z_c = \sum_{i=1}^{n} \frac{z_i}{n} \tag{10}$$

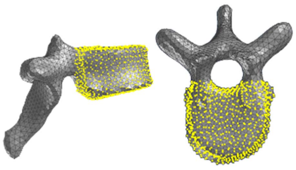

Figure 21. Definition of vertebral body

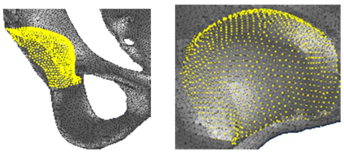

Figure 22. Nodes to derive centre of acetabulum

Table 3.
Keywords for connection of sensor nodes to surrounding structure

Code	Keyword	Recommended Parameters
LS-DYNA	*CONSTRAINED_INTERPOLATE	DDOF = 123456, CIDD = 0, ITYP = 1, IDOF = 123, TWGHTi = RWHGTi = 0
VPS	OTMCO_/	DOFCOD = 111000, IMETH = 0, IELM = 1, ITYP = 0, RADIUS = 0, WTFAC = 1
RADIOSS	/RBE3	I_MODIF = 2 or 3, WTi = 1, TRAROT_REFi = 111111, TRAROT_Mi = 111000
ABAQUS	*MPC	BEAM, NSET1, NSET2

FCR 30 km/h

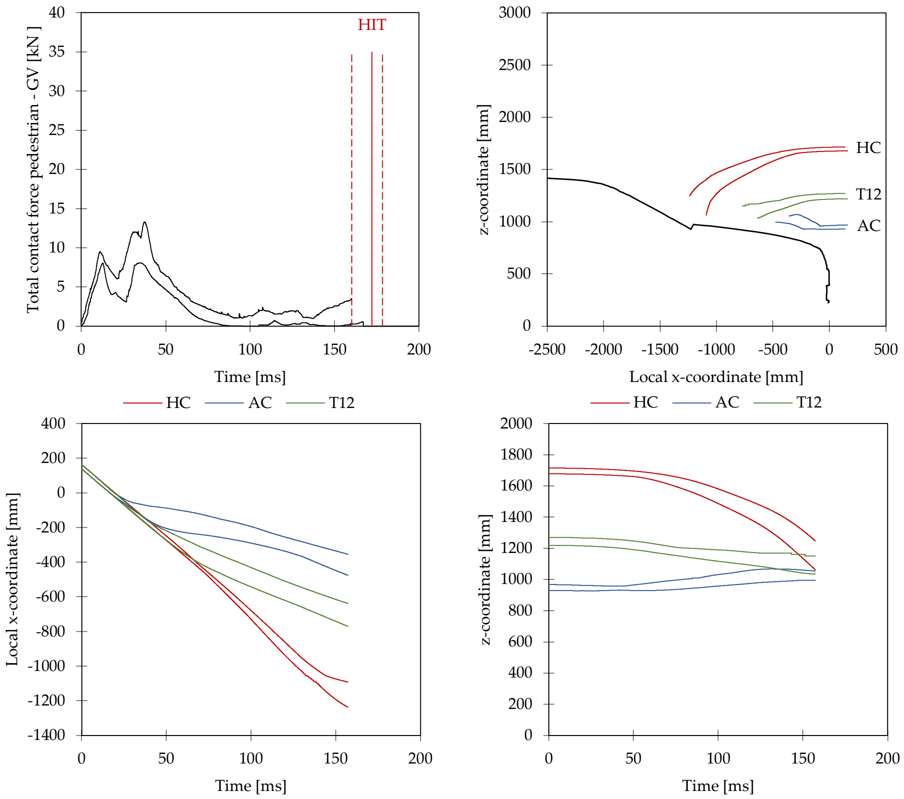

Figure 23. Corridors for impact with generic FCR model at 30 km/h – Reference HIT *= 172.3 ms.*

FCR 40 km/h

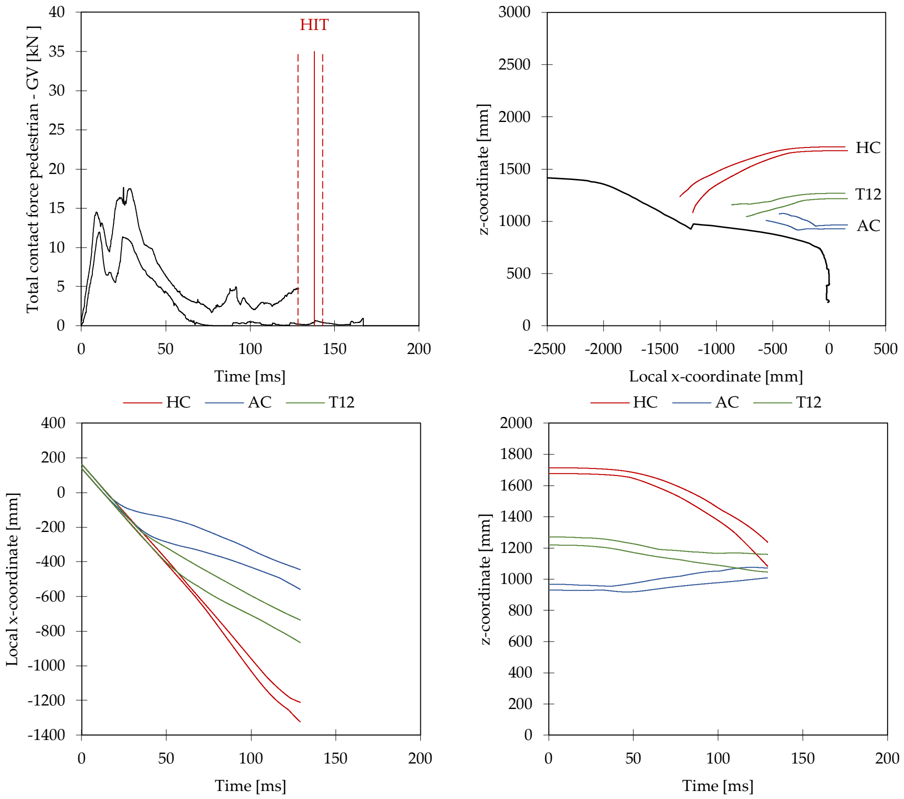

Figure 24. Corridors for impact with generic FCR model at 40 km/h – Reference HIT *= 138.1 ms.*

FCR 50 km/h

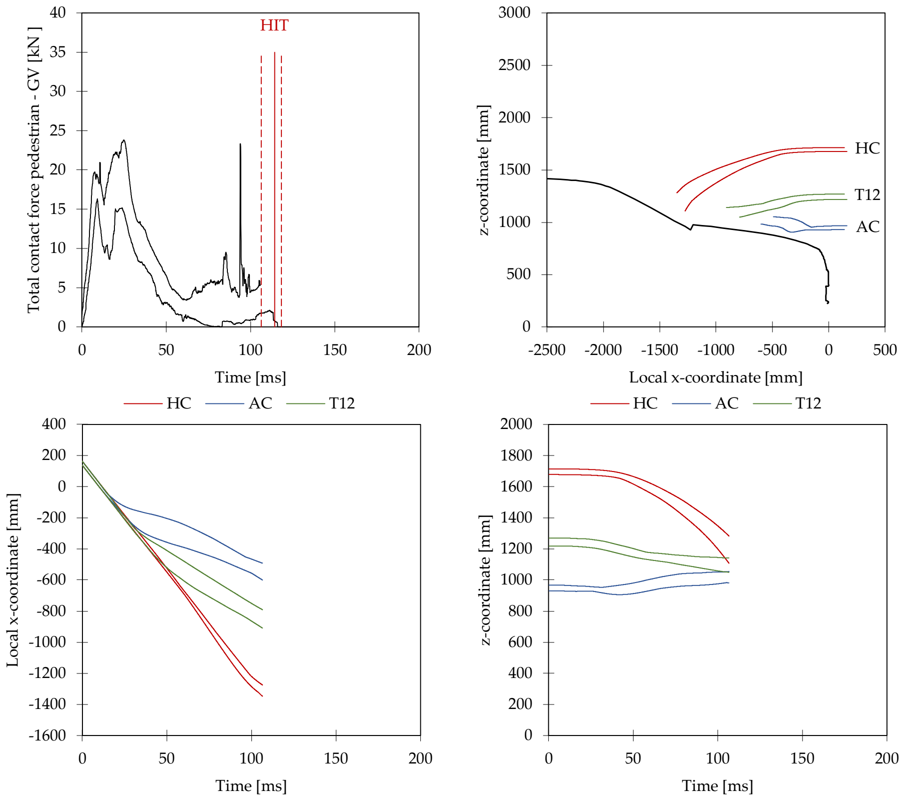

Figure 25. Corridors for impact with generic FCR model at 50 km/h – Reference HIT *= 114.3 ms.*

MPV 30 km/h

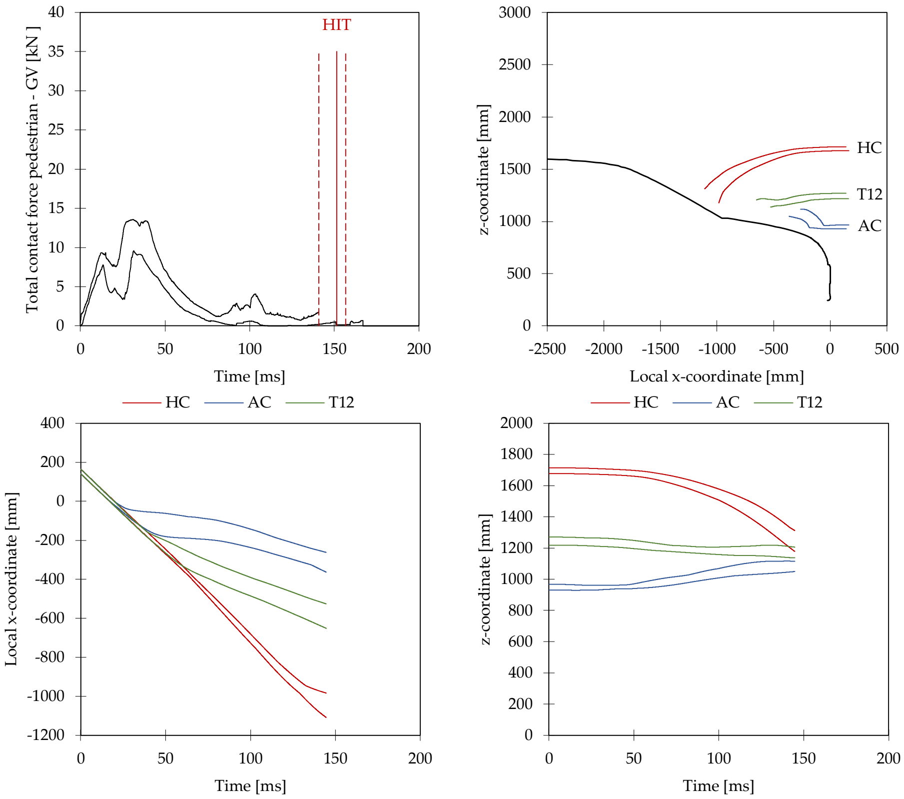

Figure 26. Corridors for impact with generic MPV model at 30 km/h – Reference HIT *= 151.5 ms.*

MPV 40 km/h

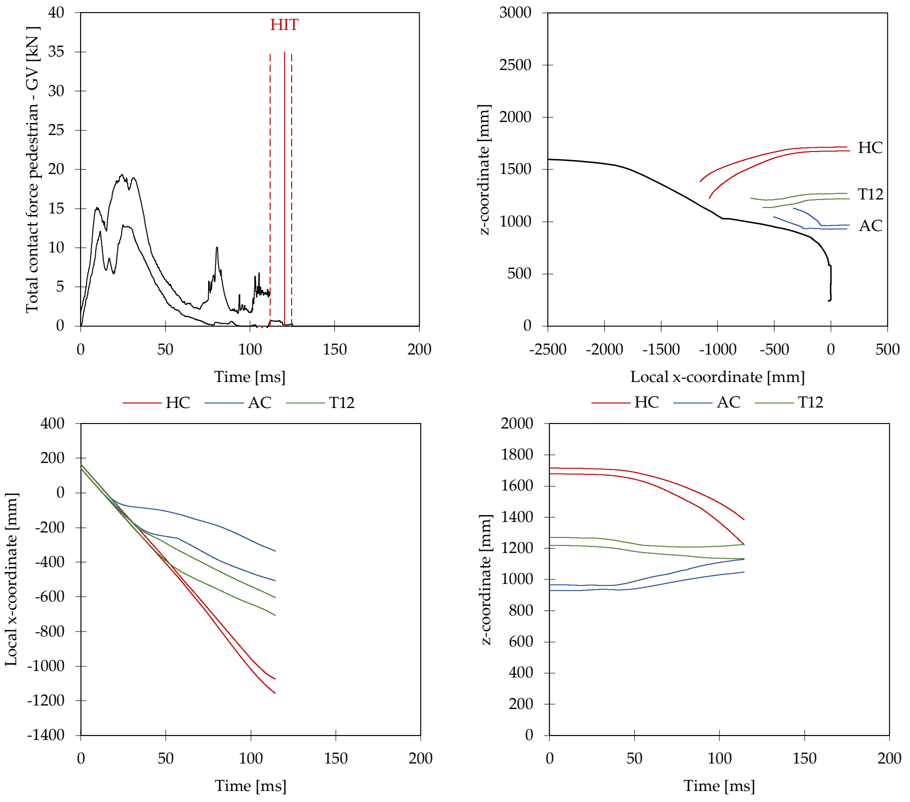

Figure 27. Corridors for impact with generic MPV model at 40 km/h – Reference* HIT *= 120.4 ms.

MPV 50 km/h

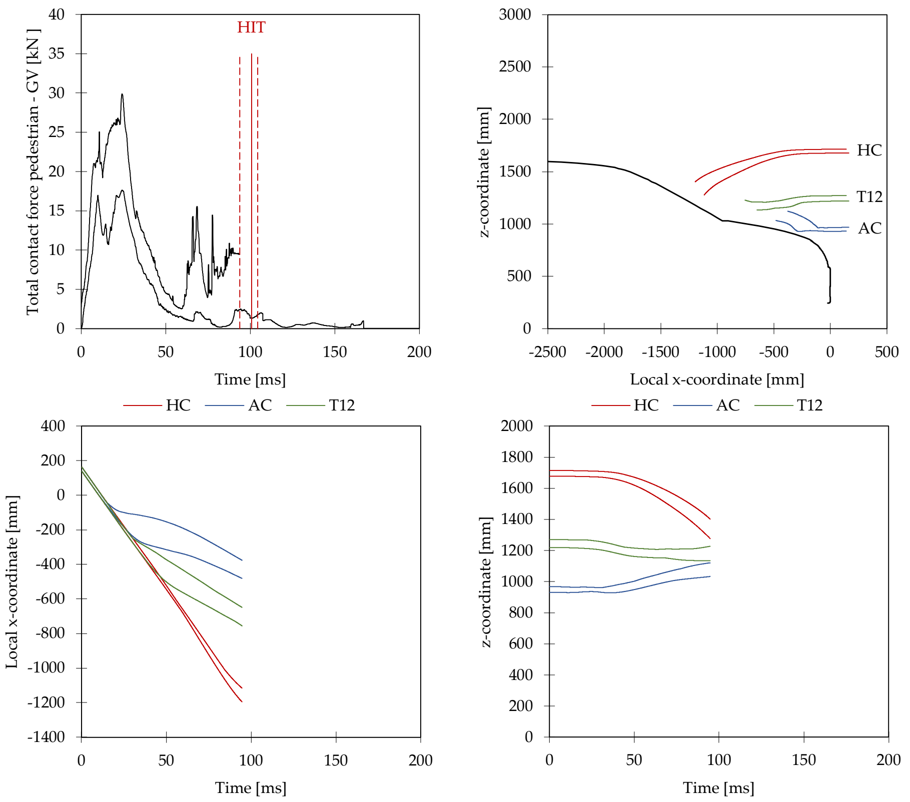

Figure 28. Corridors for impact with generic MPV model at 50 km/h – Reference* HIT *= 100.8 ms

RDS 30 km/h

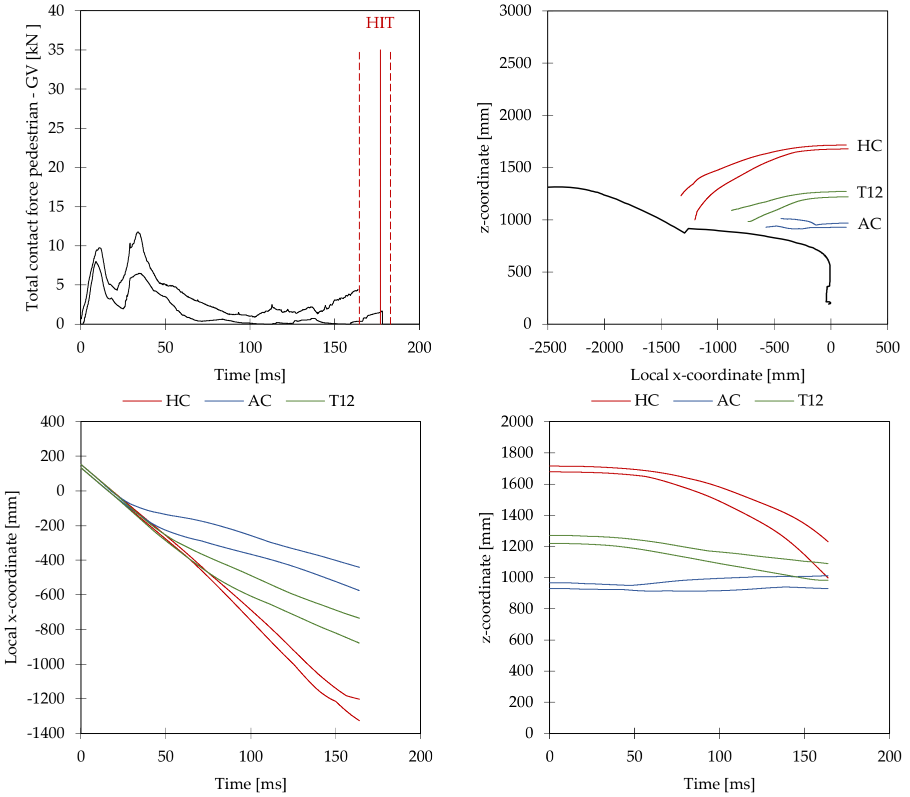

Figure 29. Corridors for impact with generic RDS model at 30 km/h – Reference HIT *= 176.9 ms.*

RDS 40 km/h

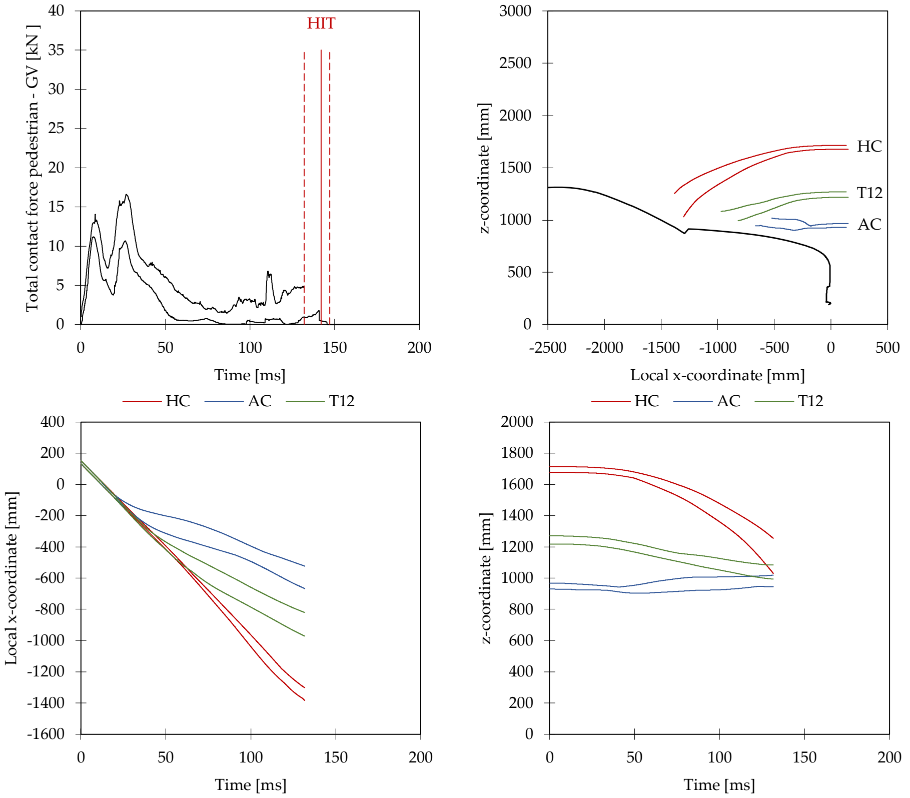

Figure 30. Corridors for impact with generic RDS model at 40 km/h – Reference HIT *= 142.1 ms.*

RDS 50 km/h

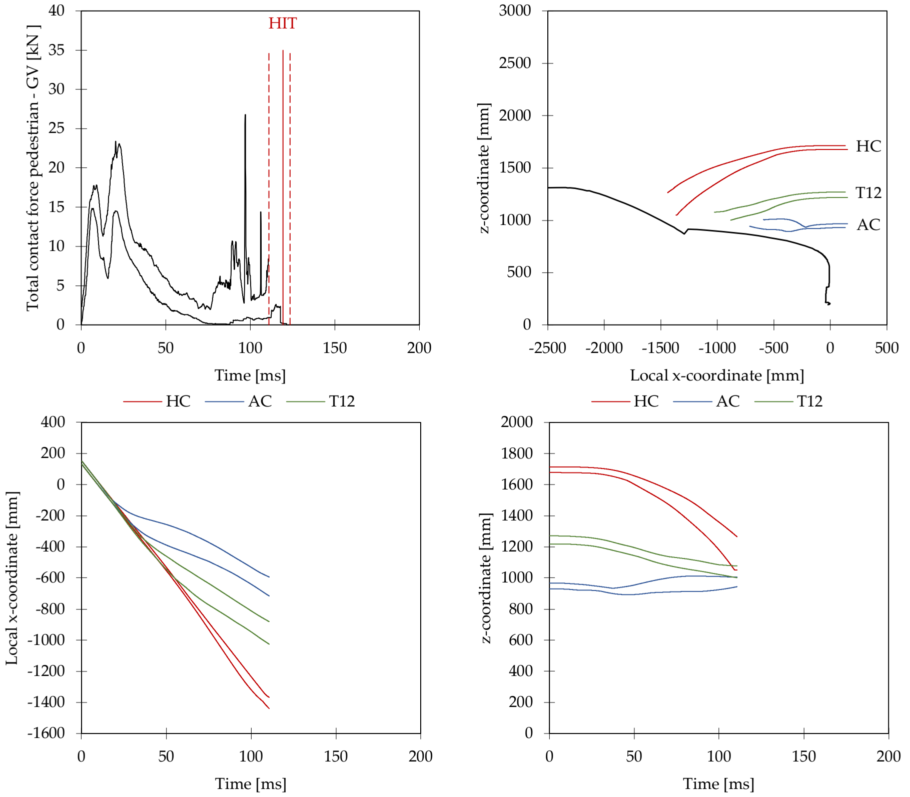

Figure 31. Corridors for impact with generic RDS model at 50 km/h – Reference HIT *= 119.3 ms.*

SUV 30 km/h

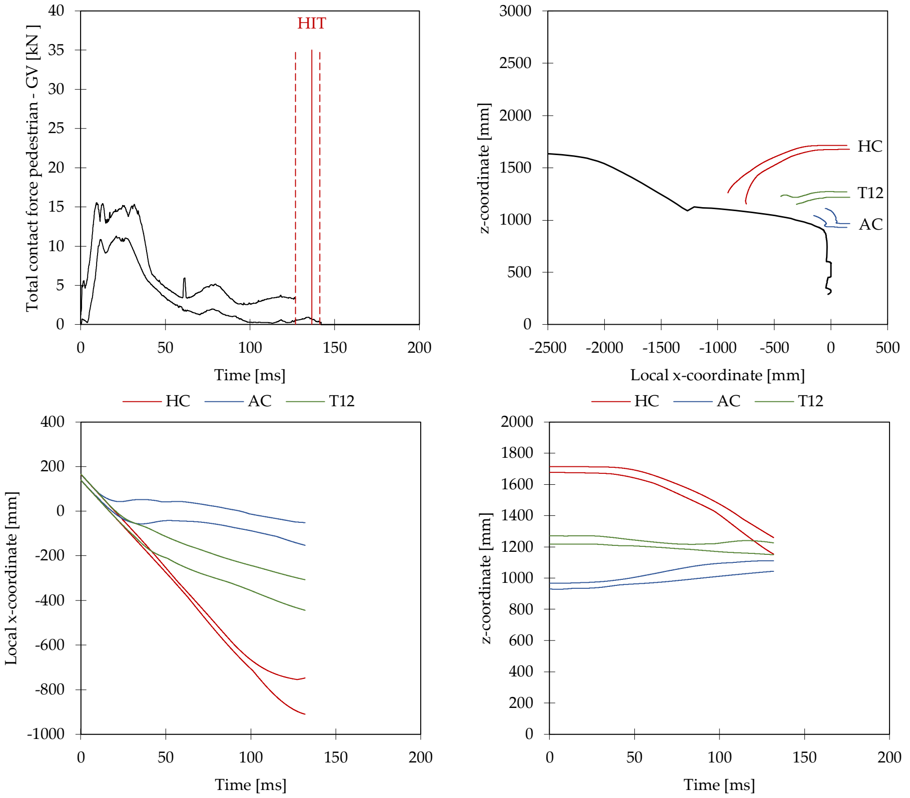

Figure 32. Corridors for impact with generic SUV model at 30 km/h – Reference HIT *= 136.5 ms.*

SUV 40 km/h

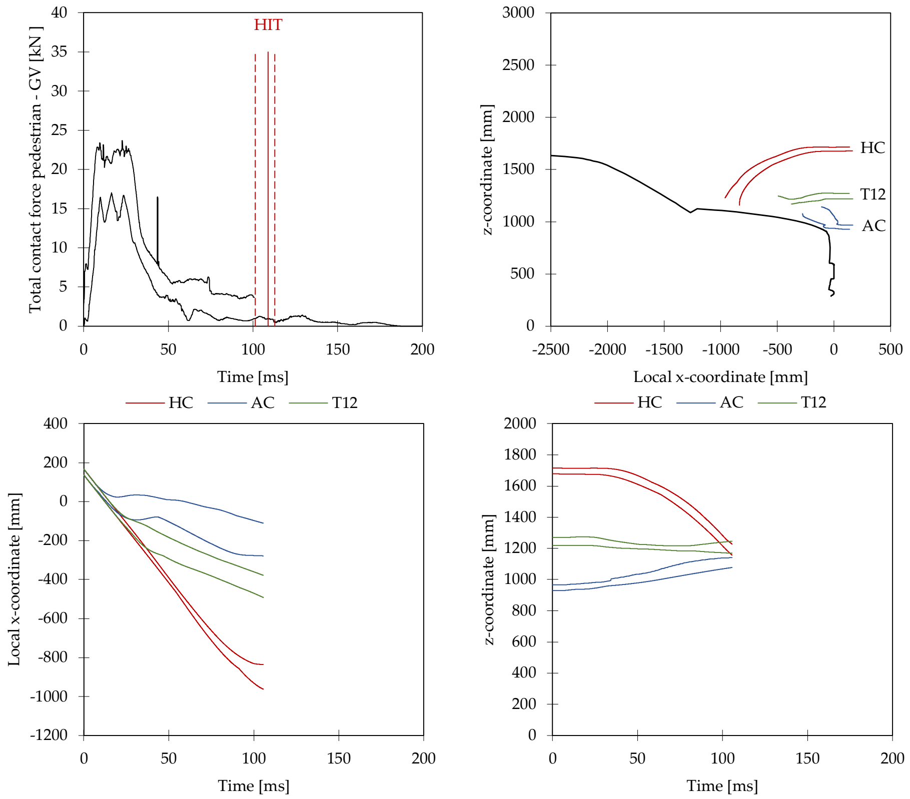

Figure 33. Corridors for impact with generic SUV model at 40 km/h – Reference HIT *= 109.0 ms .*

SUV 50 km/h

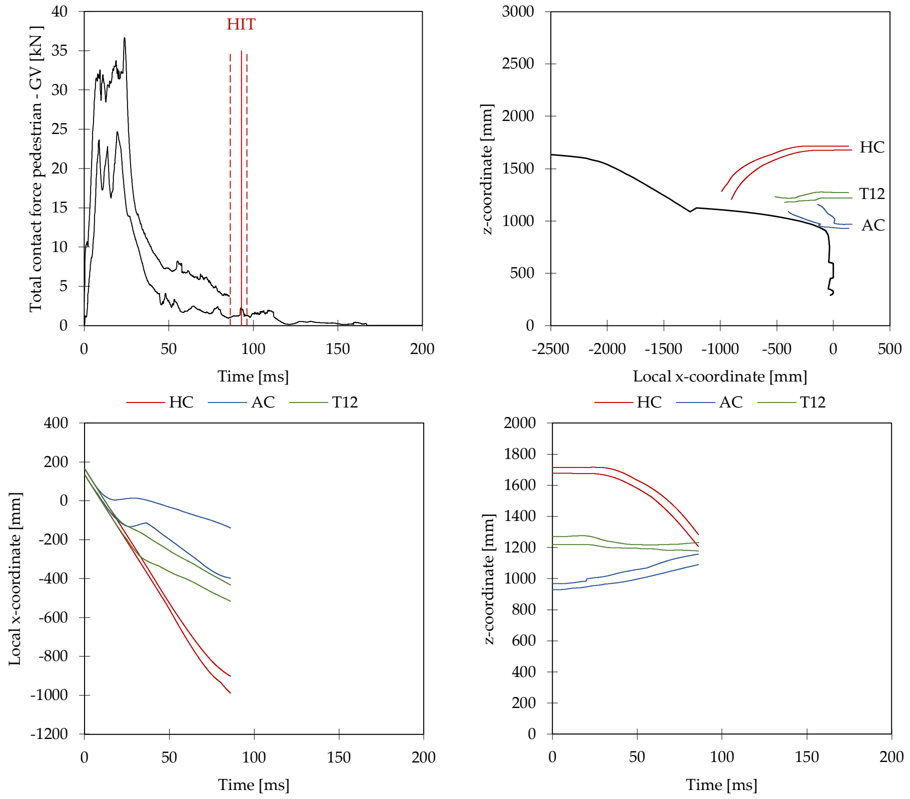

Figure 34. Corridors for impact with generic SUV model at 50 km/h – Reference HIT *= 92.9 ms*

DEVELOPMENTS IN CAR CRASH SAFETY AND COMPARISONS BETWEEN RESULTS FROM EURO NCAP TESTS AND REAL-WORLD CRASHES

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Paper Number 19-0291

ABSTRACT

Developments in car crash safety is preferably demonstrated by analyzing results from real-world crashes. Also results from crash tests can be used to show improvements in crash performance. Previous research has shown a positive development regarding safety performance. Studies from the early 2000 have shown that the European New Car Assessment Programme (Euro NCAP) consumer tests seem to predict the outcome in real-world crashes, although they consider only a part of all accident scenarios. In 2009 Euro NCAP added rear-end crash tests to the test protocol and since 2012 Euro NCAP has gradually further revised the rating protocol. It is therefore important to study developments in crash safety, and to evaluate how Euro NCAP test results correlate with real-world performance.

This study aimed to show developments in car crash safety in cars launched since the 1980s based on real-world data, and to present how Euro NCAP crash test results predict the outcome in real-world crashes.

Two-car crashes reported by the police (n=202 360) and occupant injuries reported by emergency care centers (n=57 863) to the Swedish Traffic Accident Data Acquisition database (STRADA) were analyzed. The cars were categorized in 5-year periods, according to the year of introduction. Developments were studied in terms of risk of any injury, risk of serious injury, risk of fatality, and risk of permanent medical impairment (PMI). Correlations with Euro NCAP test results were evaluated based on star levels for all categories of injury severity.

It was found that vehicle crashworthiness has improved steadily over the years studied. The proportion of serious injuries was found to be reduced, as well as the injury risk for all injury severities studied. In a comparison of car models launched 1980-1984 with those launched 2015-2018 the proportion of AIS 3+ injuries was 67% lower. Furthermore, the risk for serious and fatal injury was 58% (+/-17%) lower, the risk for fatal injury was 88% (+/-57%) lower, and the risk for PMI was 73% (+/-14%) lower. It was also shown that Euro NCAP crash test ratings mirror real world injury outcomes for all injury severities studied. Comparing 5-star with 2-star rated cars, the proportion of AIS 3+ injuries was 34% lower. Furthermore, the risk for serious and fatal injury was 22% (+/-4%) lower, the risk for fatal injury was 40% (+/-16%) lower, and the risk for PMI was 42% (+/-4%) lower.

Large improvement in crash safety was found, especially regarding the risk for fatal injuries and injuries leading to PMI. Euro NCAP star ratings were found to well mirror the risk for fatal injuries and injuries leading to PMI.

Consumer crash tests play an important role for the development in car safety. It is however important to continuously study how well these consumer tests predict the outcome in real-world crashes. Especially considering rating systems that reward the overall safety of a vehicle, such as the Euro NCAP.

INTRODUCTION

Studies have shown improvements in vehicle crashworthiness over time [1,2,3,4,5]. The improvements have been shown with crash test results and real-world crash data analyses. There are several crash test programs like European New Car Assessment Programme (Euro NCAP) that evaluate the safety level of new cars using laboratory crash tests (e.g.,: USNCAP, ANCAP, JNCAP, IIHS Tests). By the end of 2018, Euro NCAP had tested approximately 600 of the most popular car models in Europe since 1994. Details of the tests and the results are available at Euro NCAP's web site http://www.euroncap.com.

The Euro NCAP star rating is based on point scores from front and side impacts, as well as rear sled tests that evaluate the car seats (added 2009 to evaluate the risk of whiplash injury). Since 2012 the protocol has been revised regarding, e.g., point score and weighting. The intention of these scores is not necessarily to predict the real-world outcome (although this is inferred from the test results), but to indicate what is the best practice (benchmarking) for an individual car model and the fleet generally. However, it is clearly of interest to continuously evaluate how the crash test results correlate with real-world outcome.

Due to test limitations, laboratory crash tests can only provide a relatively limited evaluation of the overall safety level of a specific car model. Real-world performance gives a more comprehensive picture of the overall safety level, as it covers a variety of real-world crash configurations. Over the years, a number of international institutions have conducted retrospective statistical vehicle safety ratings using real-world crash databases, such as Transport Road Research Laboratories in the United Kingdom, Highway Loss Data Institute in the USA, Used Car Safety Ratings in Australia, VALT in Finland, and the Folksam Insurance Group (Folksam) in Sweden. Folksam has regularly published car safety ratings since the 1983. The Folksam system rates the relative risk that a driver sustains an injury that leads to fatality or permanent medical impairment (PMI), across all impact directions and locations [3].

Previous studies have presented the correlation between Euro NCAP results and injury risk based on real-world crashes [6,7,8]. In these studies, police assessments of injury outcome (killed, seriously injured, minor injuries or uninjured) were used as the injury descriptors. In Kullgren at al. [8] the risk for injuries leading to permanent medical impairment (PMI) was additionally shown. The study by Lie and Tingvall [7] showed a strong and consistent correlation when the risk for a fatal or serious injury was the dependent variable, although no correlation was found for minor injuries. A significant correlation between Euro NCAP scores and Folksam car model safety ratings was shown in 2001 [6], where 4-star rated Euro NCAP cars had a lower risk of serious injury than 2- and 3-star rated cars. The study by Kullgren et al. [8] showed that 5-star rated cars had a 27% lower risk of injuries leading to PMI compared to 2-star rated cars. The corresponding figure for fatal injury was 68%.

In Swedish road safety strategies fatal injuries and injuries leading to PMI are in focus. In 1997, the Swedish parliament decided on the Vision Zero strategy with the long-term vision of no fatal or serious injuries within the road transport system [9]. The definition of a serious injury is an injury leading to PMI. It is, therefore, important to follow the improvements in the passenger car fleet with respect to injury outcome in terms of both fatality and injuries leading to PMI.

The aim of this study was to evaluate developments in crash safety in cars launched since the 1980s based on real-world injury outcomes, and to evaluate how Euro NCAP crash test results predict the outcome in real-world crashes. Various severities of injury outcome were analyzed; the risk of any injury, serious and fatal injury, fatal injury, and the risk for injuries leading to PMI, as used in the Folksam car model safety ratings.

MATERIAL AND METHODS

The Swedish Traffic Accident Data Acquisition database (STRADA) was used that covers two data sets: car crashes reported by the police, and occupant injury data from emergency care centers [10]. Relative injury risk was calculated using paired comparisons from 202 360 two-car crashes with at least one injured front-seat occupant reported by the police. In these collisions the police classified the injuries as minor, serious or fatal. The accident years were 1994 to 2018. The risk for PMI was calculated from 57 863 injured front-seat occupants in car crashes between 2000 and 2018.

Two sets of analyses were made using the same method, one covering developments in crash safety since the early 80s, and the other evaluating the correlation between Euro NCAP star ratings and outcomes in real-world crashes. To mirror the developments in crash safety, the car models were categorized in 5-year periods according to year of introduction, beginning in 1980-84 and ending in 2014-2018. The year of introduction was chosen as a way to describe the year of design. The correlation between Euro NCAP crash test scores and real-world injury outcomes was made based on the star level. For both analyses four different injury levels were studied: any injury, serious and fatal injury, fatal injury and injury leading to PMI. The following sections describe how the relative risk using paired comparisons and the risk for PMI were calculated.

Calculating the Relative Injury Risk using Police Data

Relative injury risks were calculated using the paired comparison technique for two-car crashes. The method was initially developed by Evans [11], but has been further refined by Folksam for car-to-car collisions [12,13,8]. By studying two-car crashes in which both cars were involved in the same impact, the paired comparison method controls for variation in impact severity apart from the influence of car mass. The relative injury risk for a specific group of vehicles was calculated by comparing the injury outcome for that group with the injury outcome for the vehicles they collide with. In two-car crashes, mass differences can influence the relative injury risk, as they alter the impact severity distribution between the groups. This can be taken into account in the model and the influence of mass on the relative injury risk can be controlled for.

Another factor potentially influencing the results is aggressivity. Aggressivity is defined as the properties of a vehicle other than the mass that can influence the risk of injuries to the occupants of other vehicles (its structure and stiffness for instance can have such an effect). However, the influence of aggressivity on injury risk in paired comparisons has been shown to be much smaller than the influence of mass [12,14], thus aggressivity was not adjusted for in this analysis. All car-to-car crashes were included irrespective of crash type. It was assumed that the injuries among occupants in one car are independent from the injuries among occupants in the other car, given a particular impact severity.

Using the paired comparison method, crash outcomes in two-car crashes were grouped in four groups (see Table 1), where x_1 is the number of crashes causing injuries among occupants in both cars, x_2 is the number of crashes causing injuries in the case car only (but not in the other vehicle), x_3 is the number of injuries among occupants in the colliding vehicle only (but not in the case vehicle), x_4 reflects the situation that no one is injured in the crash (often little data are available here). In calculating the relative risk, x_4 is not used, as it does not add any important information.

Table 1.
Number of impacts with different combinations of injured drivers in Car 1 and Car 2

		Driver of Car 2		Total
		driver injured	driver not injured	
Driver of Car 1	driver injured	x_1	x_2	x_1+x_2
	driver not injured	x_3	x_4	
Total		x_1+x_3		

The unadjusted relative risk between the studied car or group of cars and its collision partners is calculated as the ratio between injuries in the studied car compared with the injuries in its collision partners (Equation 1). The collision partners are considered to be a sample of the whole car population, and therefore they provide the exposure basis that allows for comparisons across all case vehicles.

$$R=(x_1+x_2)/(x_1+x_3) \qquad \text{(Equation 1)}$$

Compensation for Mass Differences

The influence of mass on injury outcome described by power model functions has been described extensively by Elvik et al. [15] and Krafft et al. [16]. If there are mass differences between the case vehicles and the vehicles that they collide with, both groups will be exposed to an impact severity different to that from when the two groups of vehicles have the same mass. If the case vehicle group is lighter than the other vehicle group, it will experience a higher impact severity compared to its collision partners (Impact Energy = mass * velocity^2). At the same time, the other heavier vehicles will experience a lower impact severity. The mass differential will therefore result in a benefit for one vehicle and a disadvantage for the other vehicle in a two-car crash. In order to allow for accurate comparisons and take into account the importance of mass for the case vehicles, the altered impact severity distribution for the cars they collide with must be compensated for. The adjusted relative injury risk is therefore expressed as in Equation 2. The power '*y*' in Equation 2 varies depending on the severity of the injury studied. Three mass adjustments were used depending on the injury severity; all injuries *y*=0.5, fatal and serious injury *y*=1.8, fatal injury *y*=3.5. The more severe the injury, the higher power '*y',* resulting in a steeper slope of the risk curve.

$$R_{\text{mass adjusted}} = (x_1+x_2)/(x_1+x_3) * M^y \qquad \text{(Equation 2)}$$

where M = (average case vehicle mass)/(average other vehicle mass)

Crash testing into a fixed barrier is equivalent to a crash into a car of the same mass, while the real-world outcome integrates mass as a factor that influences impact severity. In order to have a relevant comparison between crash test results and real-world performance, the influence of mass has to be fully adjusted for, considering both the case vehicle group and the group of cars that it collides with. The effect in the calculations will be that the power '*y*' in Equation 2 has to be doubled in the evaluation of Euro NCAP star ratings so that the pure safety design benefit can be isolated.

Compensation for the Year of the Crash

It has previously been found that the average safety level of vehicles in the fleet increases every year [13]. When using the paired comparison method with an accident sample including accidents that occurred several years back in time, the comparison between car models launched in different years will be influenced by this difference. By using the paired comparison method, it is possible to calculate the average decrease in injury risk of the whole car fleet. In [13,8] the average decrease in risk was found to be 1,5% per accident year as a linear relationship. For example, a car model involved in collisions 10 years back experienced an average collision partner that was 15% less safe than the average level today. This means that the rating result for that model will be 15% better than the "true" result if compared with the average safety level of models existing today. Therefore, based on these results, compensations have been made to adjust for the year of impact according to Equation 3.

$$x_{i,\text{ adjusted}} = \sum_{j=1}^{m} [x_{i,j} * (1 + f*(\text{Year}_{\text{actual}} - \text{Year}_j))] \qquad \text{(Equation 3)}$$

f = 0.015 (1.5% per year)

$\text{Year}_{\text{actual}}$ = latest accident year in the sample

Year_j = accident year for the particular crash

The accident year compensation was made for each crash with a factor linked to the accident year. The adjusted relative injury risk was calculated based on the ratio between the adjusted x_1+x_2 in the nominator and the unadjusted x_1+x_3 in the denominator, Equation 4.

$$R_{\text{year adjusted}} = (x_{1,\text{ adjusted}}+x_{2,\text{ adjusted}})/(x_1+x_3) \qquad \text{(Equation 4)}$$

The final formula used to calculate the relative injury risk from the police data would therefore be:

$$R_{\text{adjusted}} = (x_{1,\text{ adjusted}}+x_{2,\text{ adjusted}})/(x_1+x_3) * M^y \qquad \text{(Equation 5)}$$

95% confidence intervals (CI) were calculated for each risk value. The variance of the relative injury risk, R, was based on Gauss' approximation of variance for ratios.

Calculation of risk of permanent medical impairment

The risk of permanent medical impairment (RPMI) was used to measure the risk of long-term consequences [17]. The risk of sustaining a PMI of at least 10% according to the procedures used by Swedish insurance companies [18] was chosen (see Table 2). All injuries were classified according to the 2005 revision of the Abbreviated Injury Scale, AIS [19]. RPMI was based on the AIS scale, where an impairment risk has been calculated for each AIS level and body region [17].

Table 2.
Risk of permanent medical impairment in percent (from Malm et al. 2005).

Body region	**1**	**2**	**3**	**4**	**5**
Head	2.5	8	35	75	100
Cervical Spine	2.5	10	30	100	100
Face	0.4	6	60	60	n.a.
Upper Extremity	0.3	3	15	100	n.a.
Lower Extremity and Pelvis	0.0	3	10	40	100
Thorax	0.0	0	0	15	15
Thoracic Spine	0.0	7	20	100	100
Abdomen	0.0	0.0	5	5	5
Lumbar Spine	0.1	6	6	100	100
External (Skin) and Thermal Injuries	0.03	0.03	50	50	100

Table 3 shows the probabilities for permanent medical impairment for different body regions and AIS levels.

The RPMI for an occupant is calculated by multiplying the individual risks for each injury diagnose with the highest AIS level in each body region according to Equation 6, where p_i is the risk of sustaining a permanent medical impairment as a result of an injury of a certain AIS level to body region *i*. The body regions can be seen in Table 2.

$$\text{RPMI} = (1-\prod[1 - p_i])) \qquad \text{(Equation 6)}$$

Based on all reported injuries for a specific group of cars an average risk that an injury would lead to a permanent medical impairment was calculated.

Calculation of Relative Risk of Permanent Medical Impairment

The overall relative risk of receiving an injury leading to fatality or permanent medical impairment is then obtained by combining the relative injury risk and injury severity measures (Equation 7). The method has been used in Folksam's car model safety ratings since the 1990s. The latest description of the rating procedure was published by [13]. For the relative risk of PMI the 95% confidence intervals (CI) were calculated using monte carlo iterations.

$$\text{Relative RPMI} = R_{\text{adjusted}} * \text{RPMI} \qquad \text{(Equation 7)}$$

RESULTS

The proportion of serious injuries was found be reduced in modern cars. Comparing car models launched 1980-1984 with those launched 2015-2018 the proportion of AIS2+ injuries (AIS2 and more severe) was 41% lower, the proportion of AIS3+ injuries (AIS3 and more severe) was 67% lower and the proportion of AIS4+ injuries (AIS4 and more severe) was 81% lower (see Table 3).

The higher number of stars in Euro NCAP, the lower proportion of serious injuries. Comparing 5-star rated cars with 2-star rated ones, the proportion of AIS2+ injuries was 24% lower, the proportion of AIS 3+ injuries was 34% lower and the proportion of AIS4+ injuries was 66% lower (see Table 3).

Table 3.
Proportions of injuries with different AIS levels at different years of introduction and for car models with various Euro NCAP stars.

	AIS Level						
Year of launch	**1**	**2**	**3**	**4**	**5**	**6**	**Tot**
1980-1984	76,7%	13,6%	6,45%	1,71%	1,17%	0,45%	100%
1985-1989	75,9%	15,3%	5,84%	1,08%	1,32%	0,59%	100%
1990-1994	80,6%	12,8%	4,19%	1,25%	0,96%	0,14%	100%
1995-1999	82,2%	12,4%	3,66%	0,88%	0,61%	0,17%	100%
2000-2004	84,3%	11,1%	3,57%	0,58%	0,37%	0,10%	100%
2005-2009	85,9%	10,4%	3,00%	0,40%	0,25%	0,08%	100%
2010-2014	84,8%	11,3%	3,19%	0,22%	0,43%	0,14%	100%
2015-2018	86,1%	10,6%	2,58%	0,65%	0,00%	0,00%	100%
Euro NCAP stars	**1**	**2**	**3**	**4**	**5**	**6**	**Tot**
2	80,76%	13,24%	3,88%	1,05%	0,91%	0,17%	100%
3	82,31%	11,98%	4,10%	0,82%	0,69%	0,11%	100%
4	83,57%	11,74%	3,35%	0,72%	0,52%	0,11%	100%
5	85,36%	10,68%	3,22%	0,38%	0,27%	0,08%	100%
Total	83,74%	11,56%	3,45%	0,65%	0,49%	0,11%	100%

Comparing car models introduced in 1980-1984 with models introduced in 2015-2018, it was found that the risk of any injury was reduced by 40% (+/-4.5%), the risk of serious and fatal injury by 58% (+/-17%), the risk of fatal injury by 88% (+/-57%) and the risk of PMI was reduced by 73% (+/-14%) (see Table 4). Regarding the risk of fatality, the number of crashes was relatively low for the two later 5-year periods. When comparing cars introduced 1980-1984 with those introduced 2010-2014 the fatality risk was reduced by 69% (+/-15%).

Comparing 5-star with 2-star rated cars in Euro NCAP, it was found that the risk of any injury was reduced by 18% (+/-1%), the risk of serious and fatal injury by 22% (+/-4%), the risk of fatal injury by 40% (+/-16%) and the risk of PMI was reduced with 42% (+/-4%) (see Table 5).

Table 4.
Relative risk of any injury, fatal and serious injury, fatal injury and injury leading to PMI (grey column).

	Year of launch	n	mass case	mass other	x_1	x_2	x_3	R	R_{adj}	95% CI
All injuries	**1980-1984**	21018	1205	1326	8132	10274	5748	1,326	1,17	0,0108
	1985-1989	18209	1262	1341	6791	8503	5157	1,280	1,14	0,0119
	1990-1994	24980	1363	1383	8936	10294	7508	1,169	1,04	0,0108
	1995-1999	43318	1406	1424	14085	16217	13675	1,092	0,94	0,0087
	2000-2004	27290	1511	1464	7978	9278	9291	0,999	0,86	0,0115
	2005-2009	21271	1574	1498	5643	7004	7598	0,955	0,82	0,0133
	2010-2014	8340	1519	1524	2094	2732	2986	0,950	0,78	0,0216
	2015-2019	1297	1711	1557	323	367	525	0,814	0,70	0,0554
	Total	202360	1407	1409	64500	82204	64195	1,140	1,00	0,0039
Fatal and serious injuries	**1980-1984**	21018	1205	1326	998	1863	863	1,537	1,16	0,0293
	1985-1989	18209	1262	1341	812	1432	752	1,435	1,14	0,0322
	1990-1994	24980	1363	1383	890	1509	1161	1,169	0,98	0,0310
	1995-1999	43318	1406	1424	1214	2240	1969	1,085	0,89	0,0259
	2000-2004	27290	1511	1464	566	989	1236	0,863	0,75	0,0373
	2005-2009	21271	1574	1498	337	616	968	0,730	0,65	0,0462
	2010-2014	8340	1519	1524	151	264	347	0,833	0,66	0,0718
	2015-2019	1297	1711	1557	17	28	71	0,515	0,49	0,1941
	Total	202360	1407	1409	6207	11773	9100	1,175	1,00	0,0113
Fatal injuries	**1980-1984**	21018	1205	1326	24	295	96	2,655	1,56	0,0986
	1985-1989	18209	1262	1341	26	176	104	1,553	1,03	0,1169
	1990-1994	24980	1363	1383	24	170	136	1,211	0,93	0,1121
	1995-1999	43318	1406	1424	26	230	205	1,109	0,85	0,0966
	2000-2004	27290	1511	1464	11	81	134	0,635	0,56	0,1435
	2005-2009	21271	1574	1498	1	35	108	0,333	0,31	0,1858
	2010-2014	8340	1519	1524	4	25	44	0,614	0,48	0,2451
	2015-2019	1297	1711	1557	0	1	6	0,169	0,18	0,8879
	Total	202360	1407	1409	149	1361	1060	1,249	1,00	0,0396
	Year of launch	**n**	**mass case**	**mass other**	**R**	**R_{adj}**	**n RPMI**	**RPMI**	**Rel RPMI**	**95% CI**
Injuries leading to PMI	**1980-1984**	21018	1205	1326	1,326	1,17	3332	0,0489	0,054	0,0042
	1985-1989	18209	1262	1341	1,280	1,14	3701	0,0523	0,058	0,0040
	1990-1994	24980	1363	1383	1,169	1,04	8347	0,0401	0,041	0,0025
	1995-1999	43318	1406	1424	1,092	0,94	18229	0,0343	0,032	0,0016
	2000-2004	27290	1511	1464	0,999	0,86	11569	0,0299	0,026	0,0017
	2005-2009	21271	1574	1498	0,955	0,82	8524	0,0260	0,022	0,0020
	2010-2014	8340	1519	1524	0,950	0,78	2761	0,0275	0,021	0,0034
	2015-2019	1297	1711	1557	0,814	0,70	310	0,0221	0,016	0,0080
	Total	202360	1407	1409	1,140	1,00	57863	0,0378	0,038	0,0009

Table 5.
Relative risk of any injury, fatal and serious injury, fatal injury and injury leading to PMI (grey column).

	Euro NCAP stars	**n**	**mass case**	**mass other**	**x_1**	**x_2**	**x_3**	**R**	**R adj**	**95% CI**
All injuries	2	10450	1313	1381	3737	4464	3014	1,21	1,03	0,01659
	3	13437	1348	1425	4241	5337	4099	1,15	0,95	0,01558
	4	43160	1432	1445	13323	15464	13967	1,05	0,90	0,00894
	5	35419	1565	1492	9531	11801	12439	0,97	0,85	0,01029
	Total	102466	1455	1452	30832	37066	33519	1,00	0,91	0,00582
Fatal+serious	2	10450	1313	1381	393	691	441	1,30	0,96	0,04700
	3	13437	1348	1425	357	779	562	1,24	0,87	0,04653
	4	43160	1432	1445	991	1858	1921	0,98	0,80	0,02827
	5	35419	1565	1492	640	1074	1603	0,76	0,75	0,03476
	Total	102466	1455	1452	2381	4402	4527	1,00	0,84	0,01829
Fatal injuries	2	10450	1313	1381	14	79	52	1,41	0,84	0,16910
	3	13437	1348	1425	5	71	57	1,23	0,69	0,18366
	4	43160	1432	1445	24	182	203	0,91	0,70	0,10381
	5	35419	1565	1492	7	75	181	0,44	0,50	0,13640
	Total	102466	1455	1452	50	407	493	1,00	0,70	0,06857
Injuries with PMI	**Year of launch**	**n**	**mass case**	**mass other**	**R**	**R adj**	**n RPMI**	**rpmi**	**Rel RPMI**	**95% CI**
	2	10450	1313	1381	1,21	1,03	3534	0,0374	0,0386	0,00358
	3	13437	1348	1425	1,15	0,95	5392	0,0334	0,0316	0,00292
	4	43160	1432	1445	1,05	0,90	18590	0,0323	0,0290	0,00150
	5	35419	1565	1492	0,97	0,85	13152	0,0266	0,0226	0,00148
	Total	102466	1455	1452	1,00	0,91	40668	0,0310	0,0281	0,00101

DISCUSSION

These results clearly show that vehicle crashworthiness has improved since the early 80s. Such results have also been found in other studies [1,2,3,4,5]. They also show that the improvements are larger for more severe injuries. The largest improvement was found for fatal injuries, but a large improvement was also found for injuries leading to permanent medical impairment. In Sweden, which has adopted the Vision Zero approach, this is very positive, because the vision includes both fatal and serious injuries, and serious injury is in Sweden defined as an injury leading to any kind of permanent medical impairment.

The study also demonstrated that 5-star rated cars offer superior safety performance over 2-star rated cars for all types of injury severity studied. A consistent and positive correlation was found between real-world injury outcomes and Euro NCAP test results. Similar results have been seen in other parts of the world and in other studies [20,6,7,21,8]. The findings reported here though controlled for differences in vehicle mass and the year of impact using the two-car paired comparison method. Furthermore, of the previous studies only Kullgren et al. [8] was able to contrast differences in injury outcome in terms of relative risk of permanent medical impairment.

It should be stressed that as the cars were grouped by their star level, and that these results say nothing about the potential correlation for an individual car model. It is instead an evaluation of the Euro NCAP assessment principles with statistical findings from real-world crash data. While not shown here, though, a car with generally good performance in Euro NCAP was found to perform well in real-world crashes, in coherence with what has been reported previously.

The estimates in this study are based on star bands. It is important to stress that the average point performance (basis for star rating) is not necessarily in the center of the star band [7]. Furthermore the Euro NCAP test protocol has been revised in 2009 to also mirror vehicle seat performance in rear-end crashes. Whiplash injuries are very important in terms of the risk of permanent medical impairment. Swedish evidence shows that they constitute the vast majority of injuries leading to permanent medical impairment [22]. Furthermore, since 2013 it has been revised every year to also include driver assistant technologies, for example. It is important to conduct further studies to evaluate how these revisions of the test protocol correlates with real-world outcome. The Euro NCAP procedure does not try to predict the relative real-world injury risks. Instead the program is aimed at promoting the best practice in a more general way. Despite this, it is reassuring that there is good correlation between the crash test results and real-world performance, confirming Euro NCAP's relevance to vehicle crashworthiness.

It is important, however, for other studies to confirm the correlation between consumer crash test results and performance in real-world crashes to ensure that the outcome and interpretation of consumer crash tests are relevant to vehicle safety. Sweden is a small country and these findings are only possible with long exposure times before reliable data are available. A pan European co-operation using police accident records from a number of different countries would allow faster comparisons in just a few years. Studies that examine ways of undertaking such analyses would be extremely useful.

While not central to this analysis, a good score of a particular car model can be achieved in the paired comparison by being aggressive to its collision partner. While an earlier study by Kullgren et al. [14] showed that aggressivity was less important than vehicle mass, it would nevertheless be beneficial if aggressivity could be controlled for in the way that mass and age were in the current study. This would further enhance similarities between real world crash ratings and Euro NCAP scores.

The risk figures may also be influenced by systematic differences in seatbelt use and accident type. However, these factors seem not to be likely sources of error in this study, although high rated cars that normally have seat belt reminders might have a slightly higher seat belt use. This should, on the other hand, be included in modern cars to improve safety for the occupants.

It is important to stress that while the weight of new cars have gone up substantially in recent years, the results of this study confirm that improved crashworthiness has been the primary factor in enhanced vehicle safety, rather than the increase in mass. For an individual consumer though, the benefit of choosing a new car with greater mass might be larger than for the overall population, as would choosing a car with a higher Euro NCAP score or superior result in the Folksam car model safety rating.

CONCLUSIONS

It was found that vehicle crashworthiness has steadily improved over the vehicle years studied. The proportion of serious injuries was found to be reduced and also the injury risk for all injury severities studied. When comparing car models launched 1980-1984 with those launched 2015-2018, the proportion of AIS 3+ injuries was 67% lower. Furthermore, the risk of serious and fatal injury was found to be 58% (+/-17%) lower, the risk of fatal injury 88% (+/-57%) lower, and the risk of PMI was 73% (+/-14%) lower.

It was also shown that Euro NCAP crash test ratings mirror real-world injury outcomes for all injury severities studied. Comparing 5-star rated cars with 2-star rated ones, the proportion of AIS 3+ injuries was 34% lower. Furthermore, the risk of serious and fatal injury was 22% (+/-4%) lower, the risk of fatal injury was 40% (+/-16%) lower, and the risk of PMI was 42% (+/-4%) lower.

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ESTABLISHING AND COMMUNICATING RULES FOR AUTOMATED DRIVING VEHICLES

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ABSTRACT

There has been considerable confusion in the interpretation of the SAE Levels of Automation J3016, in particular when defining whether a vehicle can be classed as automated. This is particularly relevant for insurers where there is a question of liability over who was in control of a vehicle when an accident has occurred. To clarify this a set of Requirements for Automated Vehicles has been developed to give a common benchmark for consumers, manufacturers, insurers and regulators.

The approach to developing the rules has been iterative. Initially they were formulated from an insurer paper focussed on the emerging Regulation 79 UNECE steering function rules and the requirements for partial automation. The challenge of driver disengagement and driver as back-up from Level 3 automation highlighted the issue of classifying these vehicles as automated.

To address this, Thatcham Research defined vehicles as Automated or Assisted based on whether they can meet ten specific criteria for automation. The criteria are based on road safety experience, anticipated vehicle capability, consideration of other road users and the fundamental requirement that these vehicles will generate less accidents. Experience using ADAS and Assisted Vehicles helped to give practical experience of some of the challenges that needed to be addressed.

These ten requirements have now been through insurer, regulator and manufacturer challenge and review in a number of different international territories. The rules have been strongly welcomed by manufacturers and regulators who had not seen any clear guidance when the rules were first issued. They have been used in a number of European countries for insurers to lobby government for safe and insurable vehicles. At the same time the marketing and communication of the rules combined with differentiating Assisted and Automated Driving have been key to disseminating the message to the wider public. Campaigns promoted wider understanding of the differences between the new technologies and the driver's responsibility in Assisted Vehicles.

The Classification of Automated Vehicles will be a key challenge for international regulators over the next five years making the development of the rules and framework essential at this time.

BACKGROUND

The SAE J3016 Taxonomy for Automated Vehicles introduced five levels of Automated Driving Systems (ADS) which are frequently referred to in media and consumer communications. Whilst the levels allow for an evolution of automation up to fully autonomous systems, there is also a need for more clarity on when an ADS can be classified as safe to drive in an automated mode.

The levels of automation transition from Assisted Driving, where the driver is in control, through to Automated Driving where, for specific conditions, the ADS can drive without human intervention. A clear area of concern is Level 3, Conditional Automation, where the ADS is capable of driving but requires the human driver to act as a monitor and intervene as a back up.

Highly capable automated driving systems (Level 4+) will reduce the risk of accidents and present a significant future societal benefit both in terms of safety and mobility. Thatcham Research and the UK's Automated Driving Insurer Group (ADIG) recognized that an approach was needed to address the lack of clarity over safe automation to reduce the risk of an ADS being misused or misunderstood resulting in potentially catastrophic incidents. Such an incident would not only reduce the attractiveness of these vehicles for insurers but also impact the adoption and acceptance of ADS by consumers and regulators.

At the time of developing this work, no clear guidelines on the requirements for safe automated driving systems were available to regulators or OEMs. The communications developed an evolving framework for safe Automated and Assisted driving systems.

METHOD AND DEVELOPMENT

The UNECE WP29 ACSF sub-group was developing changes to Regulation 79 to address increasingly automated steering regulations. This work formed the basis of an initial technical paper 'Regulating Automated Driving' to highlight the issues of safe automation.

Starting from the assumption that a driver will want to undertake secondary tasks while the ADS is activated, it was necessary to consider under what circumstances the system could become unsafe and where clear rules and guidelines would be needed to ensure that the system would remain safe.

The adoption and influence of these rules and guidelines could only be effective if widely shared during their development - thus open sharing with OEM safety teams, regulators, insurance bodies and insurers allowed suitable challenge to the approach, framework and recommendations presented. The 'Regulating Automated Driving' document provided a technical baseline to the market on the issues recognized at that time.

Addressing Autonomous Ambiguity

A core challenge for the approach was that the SAE Levels, OEM marketing of systems and lack of consumer and media understanding created **Autonomous Ambiguity** leading to driver confusion as to the vehicle's capability and the driver's responsibility. This was summarised as vehicles needing to be either classed as **Assisted**, where the driver is always responsible, or **Automated**, where the vehicle can take over the driving task for some or all of a journey. In the UK, personal vehicle insurance policies make this critical since until a vehicle is classed as automated, traditional vehicle insurance policies apply. At the time there was no provision for insuring vehicles when driving in an automated mode.

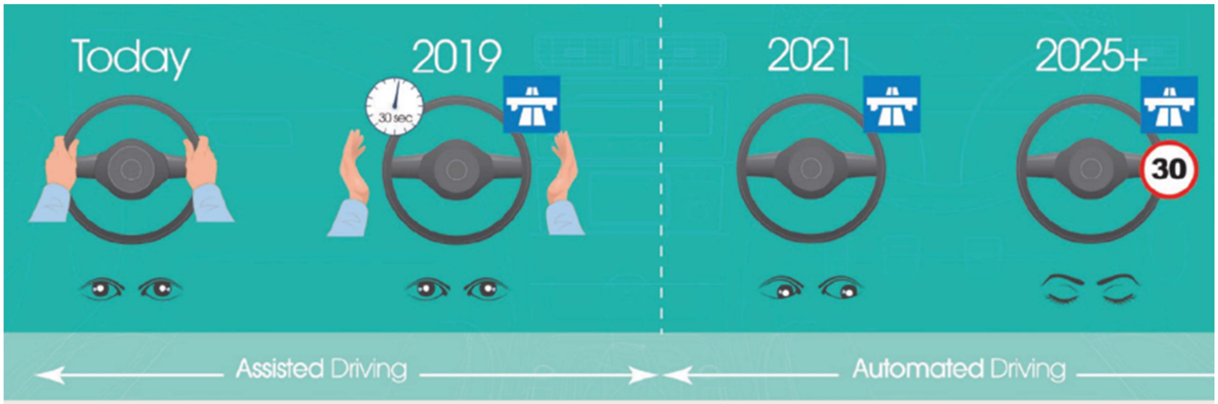

Figure 1. Assisted vs Automated Vehicles

Communication of this concept needed a simple infographic (See Figure 1) demonstrating Assisted driving with eyes on the road ahead, systems operating in a highway environment with limited hands off wheel time. Level 4 shows a disengaged driver in a single domain for level 4 awake to come back into the loop at the end of the ODD whereas Level 5 allows the driver to switch off entirely in all ODDs.

At this time international media reports of highly assisted Level 2 vehicles being misused as 'self-driving' demonstrated the combination of over-reliance on the system and confusion over the system capabilities reinforcing the need for clarity.

Establishing and Communicating Rules for Automation

Having established a clear break between Assisted and Automated vehicles, it was necessary to determine the criteria for what constituted an Automated vehicle. ‘Clarity in an Uncertain World – A Model for Automated Driving’ brought together the main elements of automated driving to allow common understanding of the issues positioned at a level which could be more widely used beyond regulatory and technical audiences.

The framework rules were built around the assumption that an Automated Vehicle will allow the driver to disengage and do secondary tasks.

If the driver can disengage from the driving task then the vehicle must be capable of driving safely in its operational design domain (ODD), a basic requirement. The system should similarly not be able to operate outside its operational design domain – so it must be geo-fenced. If it is to drive safely, it must be law abiding. Allowing a vehicle to break the law makes little sense in promoting safe automation. To ensure no confusion, the system should be named and marketed appropriately when describing its functionality. Thus Auto Pilot may be fine for Automated Vehicles but not for an Assisted Vehicle as this is misleading.

It is unlikely that the ODD will apply for every part of a journey, so there needs to be a controlled and managed timely hand-over and hand-back process between human driver and ADS. It is essential that the driver is clear whether or not they are in control of the driving task. At the same time, if the driver is needed to re-engage then the system cannot simply hand back control without warning. The vehicle needs to be capable of identifying when the ODD is coming to an end. This may happen based on location, but also where weather or road conditions end the ODD. The ADS will therefore need to manage a controlled hand-over even when the situation could not be anticipated at the start of the journey. If the driver does not take control back from the ADS, the ADS will need continue and stop safely (Safe Harbour), not presenting a hazard to other traffic, and without relying on the driver.

The need for the vehicle to be highly capable, manage handovers and be able to find safe harbour requires a sufficient level of system redundancy to be built in.

Not every event can be anticipated within systems testing. Some events will require emergency intervention. In this case the ADS should be able to carry out a minimal risk manoeuvre to attempt to mitigate or avoid a crash (in the same manner a human driver may do).

In addition to the above requirements, insurers identified the need to have sufficient data in the event of a crash to establish who was driving. Availability of near real time incident event information will be more widely needed. For example, a fault introduced through an over the air (OTA) software update could potentially affect all ADS operating the software and may need an immediate response.

The rules for automation were summarized in an infographic (See Figure 2) for easier communication to non-experts and wider dissemination to media, safety and consumer groups as well as regulatory and industry stakeholders.

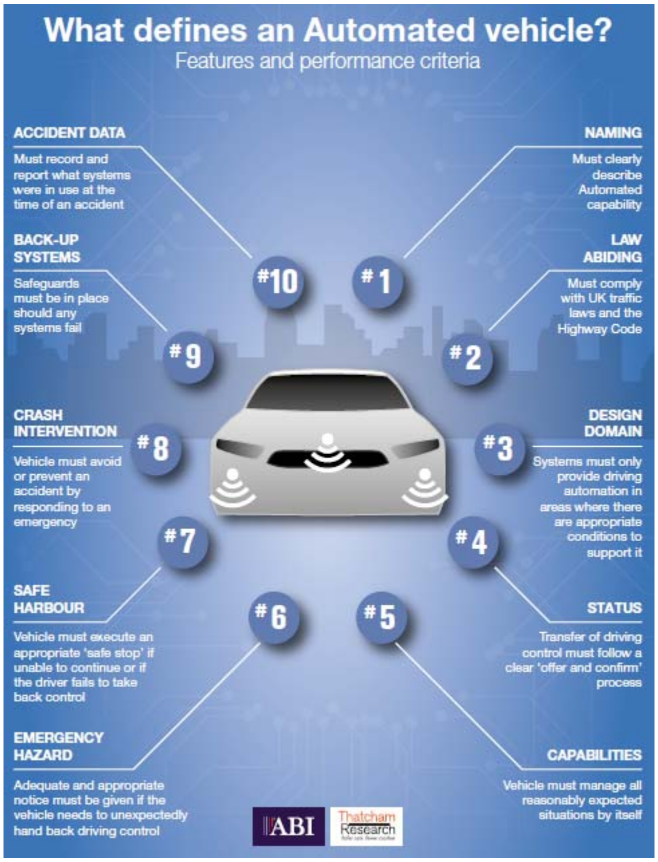

Figure 2. What defines an Automated Vehicle

Whilst the rules are useful in building a high-level framework, more detailed technical descriptions of the ten requirements outlined above were needed to support technical users. These descriptions were initially developed in a series of brainstorming sessions followed by a number of external stakeholder review iterations to ensure broad agreement with the concepts (See Table 1).

Table 1.
Detailed Criteria for Automated Vehicles

	Automated Vehicle Criteria
Naming	*The naming of the system must clearly specify automated driving.* The description of the system must be unambiguous and clearly describe the automated system functionality, limitations and driver responsibility.
Law Abiding	*Systems must abide by local traffic law including seat belt use, speed and driving behaviour.* *The system must abide by Road Traffic Laws and follow the Highway code including limiting speed to posted speed limits.* Some exceptions may be permissible to avoid a collision or to deal with a developing emergency situation. Such exceptions and anticipated vehicle behaviour must be recorded in manufacturer documentation.

	Automated Vehicle Criteria
Design Domain	*Systems must only provide driving automation in areas where there are appropriate conditions to support driving automation. Systems must indicate to the driver where automation is available.* The system must be able to determine in what circumstances it is able to offer its driver an Automated Mode of operation taking into account, for example: the environment in which it is operating (type of road, car park, private drive etc); Traffic conditions, road pavement conditions etc.; weather; connectivity; and speed limit and/or average traffic speed
Status	*Hand over and hand back must follow a clear 'offer and confirm' process between driver and vehicle with appropriate notice.* The Automated Mode is only engaged after the vehicle has understood the planned journey and/or parking manoeuvre and confirmed it is safe to operate in the Automated Mode for all or part of that journey. When Automated mode becomes available there must be a clear offer and confirm process from vehicle to driver. Similarly, the reverse must be true when the vehicle hands control back to the driver. Hand back from Automated Mode to manual driving must take place at a predetermined point in the journey (e.g. motorway off-ramp) with warnings given to the driver and a countdown timer from a minimum of 60 seconds. Driver monitoring must be in place to establish the level of driver engagement to ensure and appropriate hand over is achieved. Should the driver fail to respond to a hand back request the vehicle must execute a '**safe harbour**' manoeuvre, as described below
Capabilities	*The system must provide driving automation which safely controls the vehicle in all reasonably foreseeable driving situations within the design domain environment.* The vehicle must be able to deal with any obstruction or incident that may appear in its path and not require involvement from, or monitoring by, the driver for any part of the journey where it is in an Automated Mode.
Emerging Hazard	*If the Automated Vehicle becomes aware of a situation which was unknown at the start of automation (e.g. poor weather) and which requires a hand over to the driver earlier than planned, adequate and appropriate notice must be given.* Where such a situation arises, the vehicle must provide at a minimum a 60 second warning to the driver. The procedure must then follow that outlined for hand back under **Status** above, with the vehicle performing a '**safe harbour**' manoeuvre should the driver fail to respond.
Safe Harbour	*If the driver fails to respond to a hand back request, the vehicle must execute a 'safe harbour' manoeuvre and navigate to a safe harbour appropriate to the design domain and traffic conditions* Safe Harbour will generally be in a position away from the main carriageways In heavy traffic. In certain circumstances Safe Harbour may be to stop in lane but this will vary depending on Design Domain, traffic conditions and road speed.
Crash Intervention	*If the vehicle senses an immediate unforeseen dangerous situation the system must initiate the minimum risk manoeuvre to avoid or mitigate a collision* The vehicle must be able to use its available functionality to avoid or mitigate any collision to the best of its ability. Decisioning should be based on 'doing least harm'. It should not be expected to make ethical choices in life threatening circumstances

	Automated Vehicle Criteria
Back-Up Systems	*The system must be fault tolerant so that in the event of a fault the vehicle can continue in its Automated Mode or provide a planned system hand over to the driver.* Sufficient redundancy must be included within the vehicle systems to allow the Automated Mode to 'fail operational', that is to continue normally and safely with its journey whilst notifying the driver that an issue exists and its nature. As a minimum there must be sufficient redundancy for the vehicle to complete the planned journey in a reduced speed 'limp home' mode or to complete a controlled Offer and Confirm hand back to the driver**.** The system must have a self-diagnostic capability to detect faults and the functionality to communicate these to the driver. The system must also be capable of over the air (OTA) updates to its software or firmware and any such update deemed safety-critical must be applied automatically without any requirement for intervention or interference by the vehicle owner, operator or user.
Accident Data	*Data must be recorded in the event of a collision and made available to both manufacturer and insurer to quickly and impartially assess the status of automated systems and extent of driver input leading up to the accident.* In the event of a collision, the vehicle must be able to record, and preferably transmit the minimum dataset, described in the Clarity on Driver Status: Shared Accident Data section below, via a suitable intermediary (or 'neutral server'). For the UK it is also proposed that the that most suitable intermediary would be the Motor Insurers Bureau.

The requirements for accident data are already being progressed through the DSSAv event data proposed by UNECE. The communication documents propose that insurers have access to sufficient data to establish whether the ADS or the human driver was in control leading up to the crash. This data will only be used to confirm who or what was in control of the Automated Vehicle and not the liability between different vehicles.

The limited data request is:

- GPS-event time stamp
- GPS-event location
- Automated Status – on or off
- Automated Mode - Parking or Driving
- Automated Transition time stamp
- Record of Driver Intervention of steering or braking, throttle or indicator
- Time since last driver interaction
- Driver Seat Occupancy
- Driver Belt Latch

It is recognized that there will also be a challenge in determining accident trigger rules to generate a data event which is not currently captured in the evolving communications to date.

Extending the Framework for Assisted Vehicles

Whilst the framework rules developed had provided rules to define safe automation and a simple message for all stakeholders, requests were received to extend these to lower level Assistance, specifically Level 2 vehicles. These requests came from industry bodies seeking to bridge the gap between today's production vehicles and the future Automated systems. Since the rules for automation defined a set of features to determine whether a vehicle is automated, the assisted features allowed the team to start establishing a framework for the features of good assistance systems.

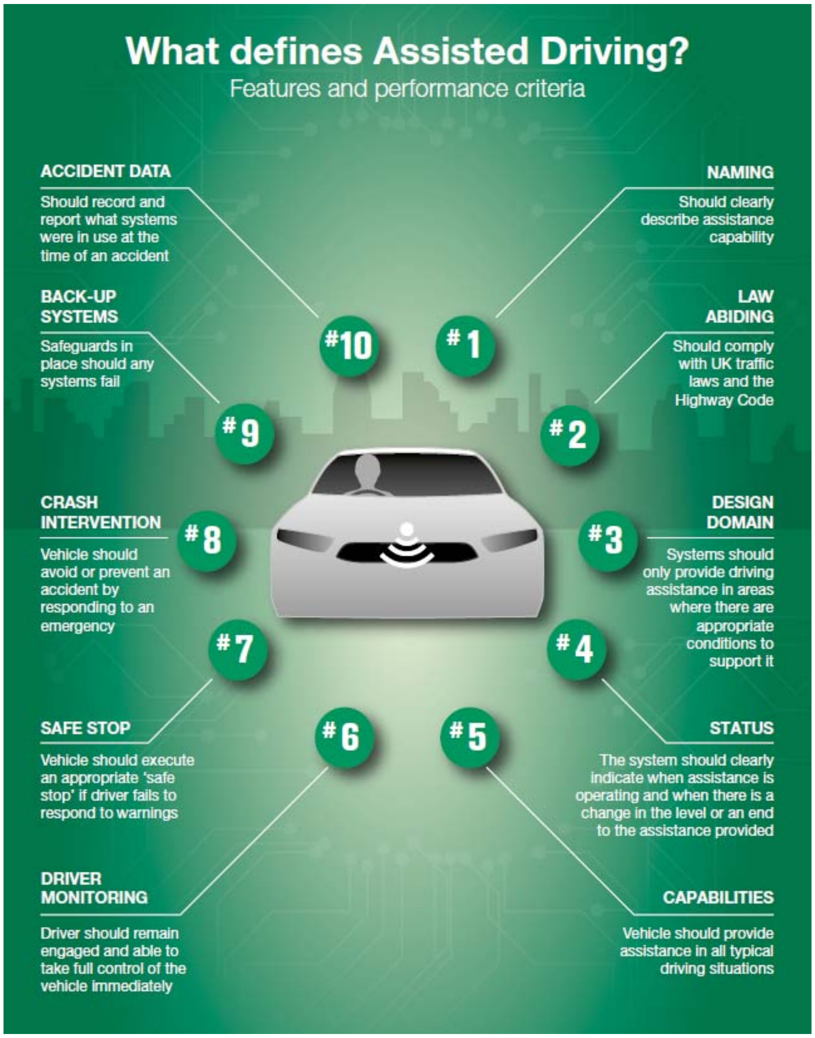

Figure 3. Features and Performance Criteria for Assisted Driving

Once again ten features were selected (See Figure 3). There were two subtle differences to reflect the lower level of capability in these systems. Firstly, the change from Safe Harbour to Safe Stop reflects the need for the system to be able to execute a safe stop if the driver does not respond to ‘hands on wheel’ warnings but also that the ADS may not have lane change capability. Secondly, the replacement of Emerging Hazard (for managed Hand-Back) by Driver Monitoring where drivers’ engagement levels can be monitored and action taken if a driver starts to disengage. Driver monitoring is of value for all systems providing increasing levels of driver support whether assisted or automated – as the driver’s workload decreases they are more likely to start disengaging from the driving task creating a less safe system overall.

Once again the Technical Assessment document gave lower level detail for specialists and provided contrast to the automated rules. Note the language is framed as systems ‘should’ rather than the ‘will’ language used in the Automated rules. (See Table 2)

Table 2.
Detailed Criteria for Assisted Vehicles

	Assisted Driving Criteria
Naming	*The naming of the system should not specify, suggest or indicate automation.* The description of the system should be unambiguous and clearly describe the assistance system functionality, limitations and driver responsibility.
Law Abiding	*Systems should only provide driving assistance when driving in accordance with local traffic laws relevant to seat belt use, speed and driving behaviour.* The system should default to the speed limit on activation or current speed if lower, provide Intelligent Speed Adaptation (ISA) and overspeed warnings. A clear warning should be displayed to the driver if driving with Assistance while contravening local traffic law.
Design Domain	*Systems should only provide driving assistance in areas where there are appropriate conditions to support driving assistance.* The vehicle should not operate in areas determined as inappropriate by the manufacturer. This will be supported by clear and robust manufacturer documentation. The system should be geo-fenced to those roads and/or locations where it is deemed safe to operate.
Status	*The system should clearly indicate when assistance is operating and when there is a change in the level or an end to the assistance provided.* There should be a clear, commonly used display of Continuous Assistance statuses. Required statuses include: Enabled, Available, Engaged, Disengaged, Driver Intervention Required
Capabilities	*The system should provide driving assistance which assists with the safe control of the vehicle in all typical driving situations within each Design Domain* The system should provide driving assistance that delivers safe lateral and longitudinal support to guide the vehicle along the road taking into account other road users. If a situation is encountered that it is unable to cope with, then a clear and timely warning should be given and ideally the hand over completed in a controlled manner.
Driver Monitoring	*Driver monitoring should ensure that the driver remains engaged in the driving task and able to take full control of the vehicle immediately. Ignoring warnings should lead to system deactivation.* While system is engaged the driver should be monitored to ensure that they remain present and able to control the vehicle. Driver inactivity or inattention should require an escalating cascade of warnings to re-engage the driver
Safe Stop	*If the driver fails to respond to the escalating cascade of engagement warnings, the vehicle should execute a safe stop.* Safe stop should vary with the design domain and traffic conditions. The system should provide appropriate warnings to other drivers to minimize the risk of stopping (e.g. hazard warning lights). An eCall event must be triggered
Crash Intervention	*The vehicle should be equipped with collision avoidance systems capable of preventing or mitigating an emergency situation likely to result in a crash.* The vehicle should be able to react to any such situation, using its available functionality to avoid or mitigate a collision to the best of its ability. Technology to address collisions with other vehicles and vulnerable road users includes, for example, AEB and lane support systems for lateral control.
Back-Up Systems	*The assistance system should clearly indicate to the driver a reduction in assistance as a result of vehicle sensor or system failure.* System should provide sufficient warnings if the system becomes unavailable and should be capable of a controlled hand back to the driver
Accident Data	*Limited data set should be provided in the event of an accident.* Where data can be made available, this should be provided in line with DSSAV specifications.

Communication Timeline and Media Coverage

The communication timeline for publications and associated media activity to date is summarized below .

July 2017 – **Regulating Automated Driving** [1] - R79 Strategy Document – laying out issues – fed into the UK Automated and Electric Vehicle Bill (AEVB) to ensure Insurance needs addressed.

November 2017 – **Clarity in an Uncertain World** [2]– first iteration of 10 Rules of Automation Framework

May 2018 - Publication of **Assisted and Automated Definition** [3] – Framework doc defining both insurance issues and ten criteria for Automated and Assisted vehicles. This formed the basis of defining a test procedure for Insurers and Euro NCAP as well as wider adoption by International Insurers – GDV FFA IBC

June 2018 – Presentation '**Assisted and Automated Driving – International Insurance Views**' by Matthew Avery to UN ECE WP29[4]

The Assisted and Automated Definition launch attracted significant media attention worldwide with 250 pieces of coverage in the week following launch with a reach of more than 550 million. Pre-launch interviews/demos were conducted with BBC News[5], WIRED, The Guardian, Insurance Times and Press Association. Key broadcast coverage included BBC Breakfast, Radio 4 Today programme, BBC national and regional news updates, plus BBC Online. Worldwide the launch was covered in more than 20 countries, across national and technology media, especially within US. Social media generated over 320k video views on YouTube and social channel plus tens of thousands of social posts/commentary. Overarching sentiment across all media was that terminology used needed to change.

DISCUSSION AND LIMITATIONS:

The development and communication of the Assisted and Automated Driving rules has been very successful in breaking some of the public misunderstanding of both the vehicles and the media messaging. The rules are intended to be a benchmark which will continue to grow and evolve as the technologies come closer to publicly available vehicles and approval standards.

There is an ongoing challenge to build consumer understanding that will need to be reinforced as we move towards the first Automated Vehicles in particular providing sufficient education and support in promoting safe system usage.

This work continues to be built on. The next iteration will be a further level of technical detail to produce a Definition of Safe Automated Vehicles with a more regulatory level of detail. It is likely that this document will lay out detailed criteria to establish what threshold a Level 3 vehicle would need to reach to be classed as Safely Automated.

CONCLUSION

Although the communications outlined in this paper have evolved with the fast pace of technology, there is still considerable work to do to ensure the development and adoption of safe automation is achieved. The 10 rules of automation have provided the basis for a framework for regulators, OEMs and safety test development. This will need to continually evolve as AD systems come closer to market and regulation of ADS moves forward.

We recognize that there is also considerable work to do to build understanding within the general population who do not have a sufficient understanding of the likely benefits and limitations of Automated Vehicles. However, we also need to recognize that the work already undertaken has helped to build a common baseline for regulators, OEMS insurers and other stakeholders to work from.

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THE DEVELOPMENT OF A EURO NCAP FAR SIDE OCCUPANT TEST AND ASSESSMENT PROCEDURE

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Paper Number 19-0278

ABSTRACT

The European New Car Assessment Programme (Euro NCAP) has been evaluating side impact protection since 1997. The original side impact test procedure utilised the EuroSID anthropometric test device (ATD) and Multi 2000 barrier face. In the year 2000, the side impact assessment was expanded to incorporate the perpendicular pole impact test. Both procedures were upgraded in 2003 to use the ES-2 ATD and Advanced 2000 barrier face in the side barrier impact. The most recent update to the side impact test procedures saw the adoption of the WorldSID 50th male ATD and the Advanced European Mobile Deformable Barrier face (AE-MDB) along with the oblique pole impact in 2015. To date, the adult side impact assessments have focussed on struck-side impact protection with the use of a driver dummy only and two child occupants in the rear.

A number of European research projects have interrogated accident databases to establish the nature and magnitude of the risks to far-side occupants. In 2015, the Euro NCAP Board of Directors agreed that the level of side impact protection offered to drivers and front seat passengers should be improved and the Euro NCAP Side Impact Working Group (SIWG) was tasked with addressing far-side occupant protection. The group was asked to draft an updated far-side impact procedure that could be incorporated into the existing assessment regime without significantly increasing the test burden. The focus of the new procedure is on passengers seated in the front row and will evaluate excursion and contact injury risk. The new assessment is sled based rather than being a full-scale test, allowing for a wider coverage of real-world scenarios and offering a method for the development of countermeasures in the most effective and efficient way.

This paper details the group's work in the development of a far-side occupant test procedure. The outcome of real-world accident analyses from numerous European databases has been summarised along with a review of existing work already undertaken for far-side occupants. This data allowed for boundary conditions to be established, which were evaluated by the group with the use of physical and CAE testing. The outcome of this research has been used to develop a Euro NCAP assessment procedure for non-struck side front seat occupants.

BACKGROUND

In 2009, Euro NCAP identified that the side impact test procedures should be more reflective of the high number of deaths and seriously injured occupants that are seen on the road [1]. Euro NCAP subsequently updated the front and side impact test procedures in 2015. The changes were aimed at promoting restraint systems that were more advanced and more robust for the driver and all passengers. Further updates to the front and side impact procedures will also be applied in 2020 as front and side crashes will continue to dominate traffic accidents in terms of the killed and seriously injured [2]. Advanced avoidance technologies are emerging that can mitigate typical head-on and crossing scenarios, but the requirements are technically very challenging. Crash protection remains essential and Euro NCAP continues to promote excellent structural and restraint system performance, even where advanced driver assistance systems are offered.

Euro NCAP's overall goal is to incrementally improve the assessment of crash protection so that it can continue to reward those vehicles that provide the best possible protection against serious and fatal injuries. An in-depth analysis of crashes in Europe performed by ADAC for Euro NCAP highlighted several areas where vehicle manufacturers might improve general vehicle design. One key area was the protection of car occupants in far-side crashes. In 2016, Euro NCAP created a group dedicated to developing a far-side test and assessment procedure. The membership of the group consists of Euro NCAP members, official test laboratories and industry representatives from ACEA and CLEPA.

PREVIOUS RESEARCH

The first step taken by the group was to review existing data on far-side impacts. There have been a number of studies published over the years on far-side occupants, yet side impact test procedures and the resulting protection offered by vehicles still focus on the struck-side occupants.

A study performed by Fields et al identified the high risk to far-side occupants from head contacts with vehicle structures on the struck-side [3]. In 2006, the European 6th framework project for Advanced Protection Systems (APROSYS) published a methodology to address non-struck side injuries [4]. This project reviewed real-world far-side crashes that were contained in several accident databases including CCIS, GIDAS and ZEDATU. The accident data indicated that the head and torso suffered AIS3+ injuries three times more frequently than any other body region. As with the study from Fields et al, the side structure, belt/buckle and adjacent occupants were the most injurious hazards. An examination of the impact characteristics indicated that, in most cases, the direction of force was perpendicular to the vehicle centreline. Regarding velocity, in order to address 50% of all non-struck side occupants with MAIS2+ injuries, a delta V of 41km/h would be required. In 2008, the European Enhanced Vehicle-safety Committee (EEVC) Working groups 13 and 21 produced an overview of side impacts using data from the United Kingdom, France, Germany and Sweden [5]. Of all the occupants in single side impacts analysed, 55% of occupants were on the far-side, leaving 45% on the non-struck side. A study of NASS data examined the characteristics of belted occupants with MAIS3+ injuries from far-side impacts [6]. The analysis found that 79% of drivers sustained MAIS3+ injuries with the head and chest being the most commonly injured body regions. The mean impact severity was a lateral delta V of 36km/h. The most frequent impact direction was found to be between 60 and 90 degrees.

ACCIDENT DATA REVIEW

In addition to the accident data in published literature, the group undertook additional analyses of accident data in 2016. The databases used were NASS, GIDAS, Volvo, BAAC, LAB, CCIS and ADAC. Further details of the accident data samples are contained in Appendix I. The databases contained differing injury severity levels, for example, the LAB data was known to contain higher severity impacts compared to GIDAS due a smaller vehicle fleet. As a result, the data was combined to establish general trends rather than specific conditions.

The databases were interrogated for occupants that met the following criteria:
Belted drivers and front seat passengers above the age of 10 years that suffered at least MAIS2+ and MAIS3+ injuries.

Impact conditions

The data showed that for MAIS2+ injuries the impact opponent was another vehicle in 70-86% of cases. Narrow object (pole) impacts were also represented in all databases and this condition was subsequently considered by the group. Figure 1 shows the impact opponent distribution average across all databases.

Although vehicle to vehicle impacts were more prevalent, data from EEVC Working Group 21 report indicated that the significance of pole impacts increases for MAIS3+ injuries and fatalities [5].

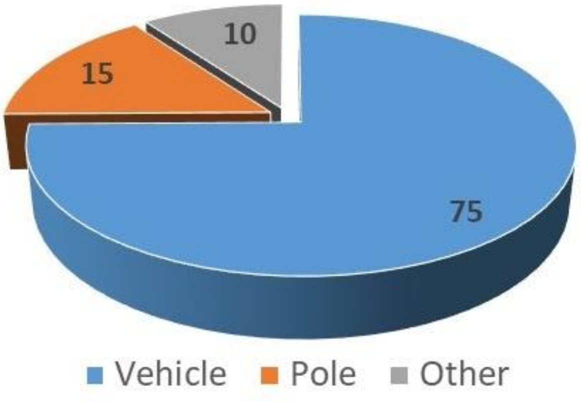


Figure 1: Impact Opponent - MAIS2+ injuries %

The impact location on the target vehicle was mostly on the occupant compartment i.e. the structures rearward of the A-pillar and forward of the C-pillar. This was the case in 64-70% of the impacts across the databases and is shown in Figure 2.

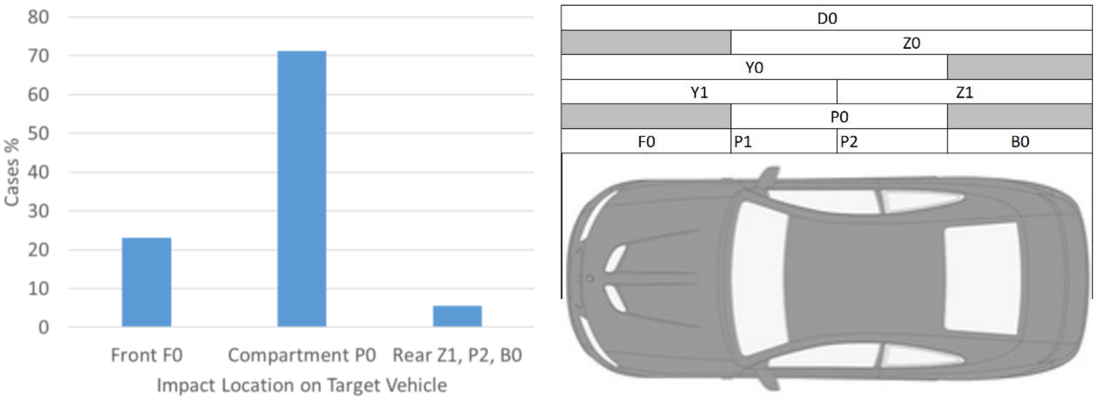


Figure 2: Impact location – MAIS2+ injuries %

Using the clock notation method, impact directions of 5 to 7 o'clock and 11 to 1 o'clock were not considered as side impacts and subsequently excluded. Of the remaining data, the mean impact angles ranged from 71 to 85 degrees. This data was similar to that reported by APROSYS (83 degrees) [2]. The impact angles should be treated with caution due to limits in the accuracy of defining impact angles. The distribution is shown in Figure 3.

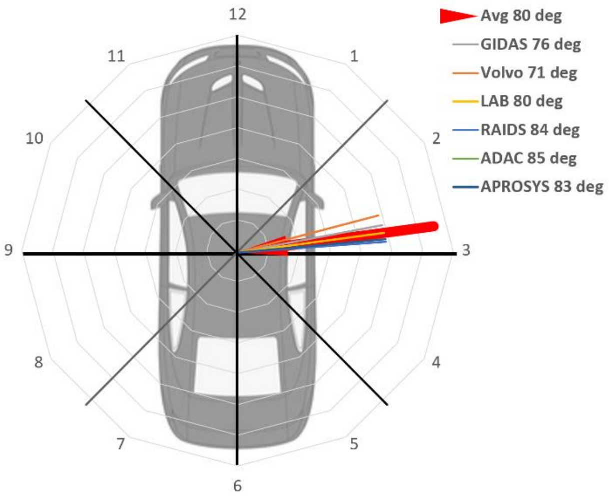


Figure 3: Impact angle

Intrusion levels showed a median level of 190mm for MAIS2+ injuries and 450mm for MAIS3+. As mentioned previously, LAB data contains more severe impacts and smaller vehicles resulting in higher intrusion levels compared to GIDAS data, see Figure 4. ADAC and NASS data indicated similar findings where the intrusion, recorded as a Collision Deformation Classification (CDC) of 3.5, covered between 50-75% MAIS2+ injuries.

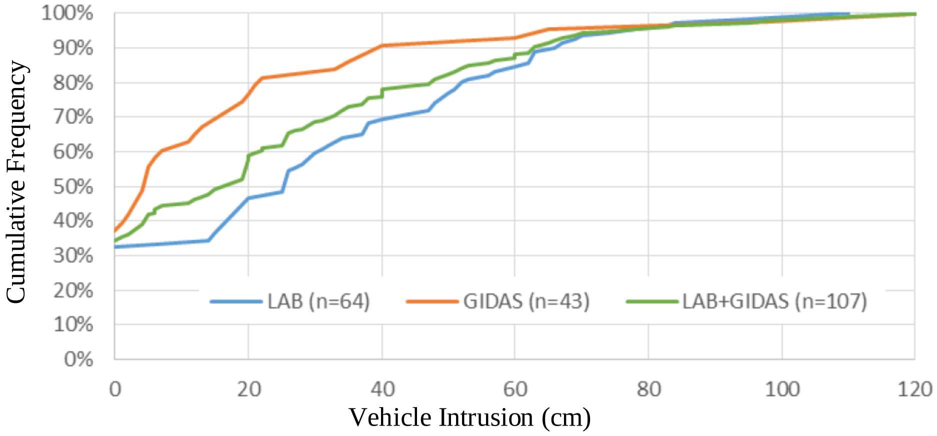


Figure 4: Occupant compartment intrusion MAIS2+

Velocity

There were some discrepancies in delta V between data sets. The accident studies reported a median equivalent energy speed (EES) for MAIS2+ of 37km/h, approximating this to a delta V of 41km/h would cover 37% of LAB data, 84% of GIDAS data and 54% of RAID-CCIS data. As there were eight databases contained in the APROSYS analysis, the report indicated that a delta V of 41km/h would address 40 to 75% of MAIS2+ injuries.

Injuries

Far-side occupants were involved in almost half of the accident cases, the data was broken down further as follows:

Far-Side: Driver, single occupancy

The injured body regions in decreasing frequency were the head, thorax and abdomen. Head injuries were mainly caused by the struck side interior and roof; the thoracic and abdominal injuries were generally caused by the seat belt system and struck side interior.

Far-Side: Driver and front seat passenger occupants

The injured body regions in decreasing frequency were the thorax followed by the head and then the abdomen, a different order to single occupancy. Head injuries were mainly caused by the struck side interior and the other occupant. As with a driver only, the thoracic injuries were caused by the seat belt system and adjacent seat.

It should be noted that the incidences of two front seat occupants were lower than those of single occupant impacts. However, the data did show that when occupant to occupant contact did occur, it was potentially life threatening. A study of NASS-CDS data indicated that in 35% of cases, head injuries were caused as a result of contact with the adjacent occupant, Thomas et al [7]. This research also conducted a sled test with two occupants (ES2-re & Bio-SID) showing that the passenger dummy recorded values multiple times higher than the established head injury criteria as a result of the far-side dummy head impacting the driver’s shoulder. Further testing also showed that the head injury risk could be greatly reduced with an airbag that deployed between the occupants.

BOUNDARY CONDITIONS

The findings of the accident analyses were used to establish a set of boundary conditions upon which a test procedure could be based. Two aspects of far-side protection were identified as necessary assessments: head excursion and occupant loading. A sled-based test was chosen over a full-scale test as this offered greater flexibility in the scenarios that could be assessed along with a more cost-efficient means of doing so. Euro NCAP already requires four vehicles to be tested destructively and adding an additional full-scale test would increase the test burden beyond what could reasonably be expected. Adoption of a sled procedure would allow for testing of multiple impact scenarios at an early stage in the vehicle development process.

Angle

As the accident data suggested a range of impact angles, it was decided that, in order to simplify the test set-up, an angle of 75 degrees would be appropriate for both pulses. It is worth noting that although the AE-MDB test is perpendicular, the barrier face design was intended to represent the most frequent impact angle observed in moving car to moving car side impact accidents [13].

Intrusion

Occupant excursion beyond the seat centreline towards the intrusion line represents a significant risk of injury. ADAC estimated that, based on a size study of 291 vehicles in seven size groups, a CDC of 3 is around 450mm of intrusion and in the area of the seat centreline. CDC was considered as an assessment measure, but it was decided that the actual vehicle intrusion recorded in the AE-MDB and pole tests would be used.

Pulse

A delta V of 41km/h would cover the majority of MAIS 2+ cases. Much consideration was given to the shape of pulse, both in terms of the accident situation and relevance in a simplified test/assessment scenario. The initial intention was to use a single generic pulse for the assessment, for example the APROSYS pulse or a combination of AE-MDB and pole impact pulses. After taking into account the variation between the AE-MDB and pole test pulses, it was decided that two vehicle specific pulses would be necessary to account for the range of vehicle masses. The group acknowledged that, depending on the vehicle size or weight, the worst-case scenario could be either the AE-MDB pulse or the pole pulse.

A simple analysis of the vehicles tested by Euro NCAP in 2015 showed that for heavier vehicles, the difference in delta V between the AE-MDB and pole impact pulses is greater than that for smaller vehicles, Figure 5. In general, heavier vehicles have a pole impact pulse that is more severe than that of the AE-MDB impact. For smaller vehicles, this difference is not so marked.

In 2020, the Euro NCAP AE-MDB test speed will increase from 50km/h to 60km/h with a trolley mass increase from 1300kg to 1400kg. An analysis of GIDAS data by BASt indicated that the current AE-MDB test speed of 50km/h only covers 20% of MAIS3+ injuries.

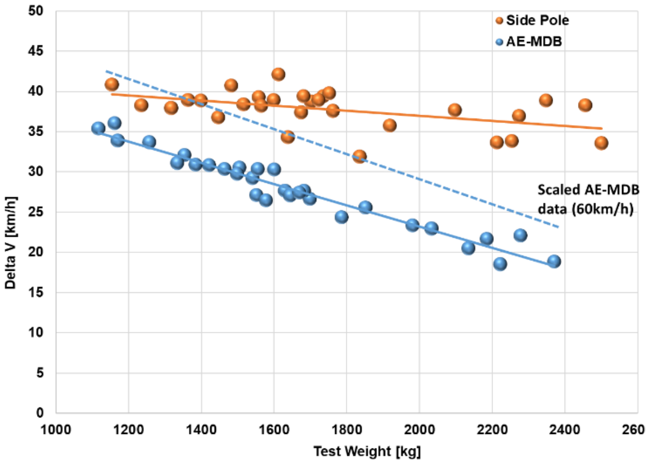


Figure 5: Delta V for vehicles tested in 2015

A speed of 60km/h would be appropriate to cover 50% of MAIS3+ injuries. The trolley mass was increased by only a small amount to be more reflective of the vehicles that Euro NCAP has tested in recent years. ACEA established, with the use of numerical simulations, that to achieve a minimum delta V of 41km/h, the AE-MDB pulse must be scaled up by a factor of 1.255 for small vehicles and 2.096 for large vehicles. For small vehicles, the scaling results in a delta V slightly above that of the pole impact but also closer to the target of 41km/h identified in the accident data. No combination of worst-case factors (e.g. AE-MDB pulse and pole intrusion) would reflect the worst-case for all vehicle sizes. Adoption of a single generic pulse test would require too many compromises that would have questionable relevance to the real-world situation. This made it necessary to consider both the AE-MDB and pole impact pulses for use in the procedure.

The AE-MDB (60km/h) and oblique pole test pulses were chosen for the procedure, Figure 6. Note, the AE-MDB pulse shown is at 50km/h. A scaling factor of 1.035 is applied to both pulses to translate to the 75 degree angle of the sled. It was acknowledged that the shape of the pole impact pulse has less relevance to real-world data compared to the AE-MDB test, but in addition to the pulse and delta V, the intrusion of the target vehicle was identified as an important factor. Higher levels of intrusion were observed in narrow object impacts when compared to vehicle to vehicle impacts. The intrusion from each impact scenario would be applied to the respective test.

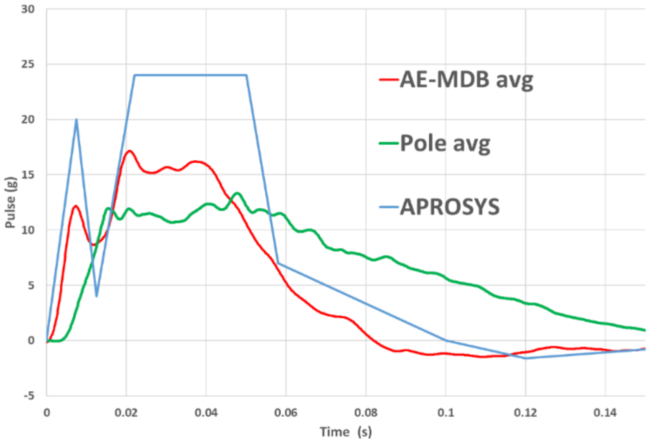


Figure 6: 2015 Average pulses and APROSYS pulse

Occupancy

A greater proportion of single occupants were injured compared to those with an adjacent occupant, 60% to 40%. To limit the complexity of the test setup, a single occupant was chosen for the test. A comparison of five different side impact dummies and post mortem human subjects (PMHS) performed by Fields et al indicated that although all of the dummies had limitations in far-side impacts, the WorldSID 50th male ATD seemed to offer improved performance compared to the others [3]. The work of the SIWG was conducted when availability of the WorldSID 5th female was very limited. The adoption of the WorldSID 50th male by Euro NCAP in 2015 and its availability across the official laboratories meant that this ATD was an obvious choice for the far-side procedure. All further references to WorldSID in this report are to the 50th male stature.

PRELIMINARY SIMULATIONS

In order to gain a basic understanding of the loading and excursion the WorldSID would be subjected to under the conditions identified by the group, a series of generic sled tests and equivalent simulations were performed. Simulation work began with the sled tests to validate the CAE model. Details of the set-up are contained in Figure

7 and Appendix II. Apart from a small amount of additional excursion in the CAE model compared to the dummy, the simulation of the WorldSID gave an adequate representation of the dummy kinematics. A further series of ten simulations was performed with a combination of the three pulses detailed in Figure 8, two impact angles and different centre consoles (rigid and none) were also used. The configurations used were as follows:

Pulse	**Angle**	**Centre console structure**
APROSYS pulse	90 deg & 80 deg	Rigid & none
Average AE-MDB 2015	90 deg & 80 deg	Rigid & none
Average Pole pulse 2015	75 deg	Rigid & none

The belt pretensioners were fired in all simulations

Figure 7: Sled and CAE

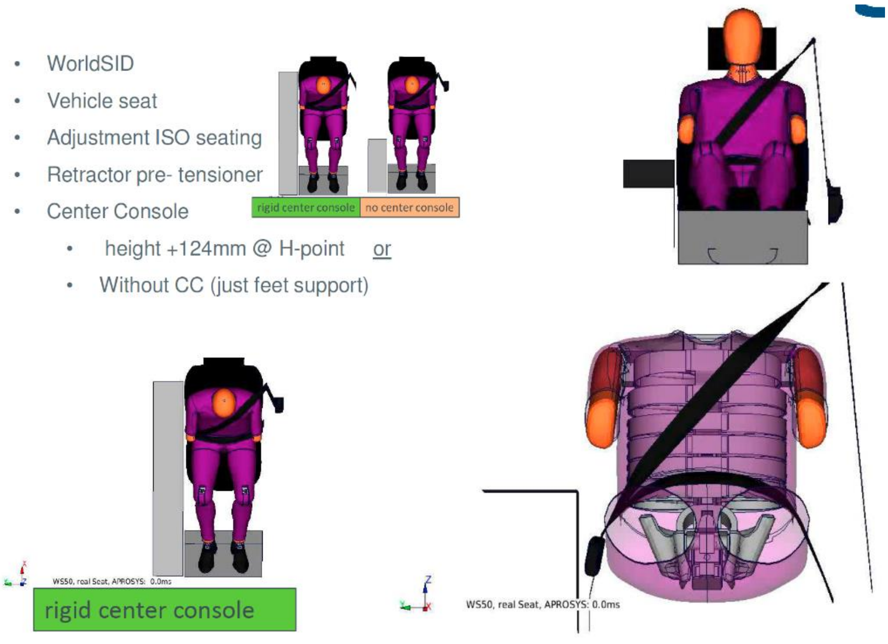


Figure 8: Simulation set-up

As this work was only intended to provide a basic level of information of how the WorldSID performed under the aforementioned conditions, the results were limited to the influence of a centre console and an analysis of head excursion. Only a limited amount of information is available in this paper regarding dummy outputs. The APROSYS and pole impact pulses generally have a higher delta V than the AE-MDB at 50km/h, even for smaller vehicles. Where there was no centre console, the head excursion increased in the lateral and downwards directions compared to when a centre console was present. The thorax and abdominal rib deflections were highest with the centre console and higher delta V. However, they were well below the Euro NCAP higher performance limits (28mm and 47mm respectively) and not at a level shown in the accident analyses. Pure belt loading was observed in the cases without a centre console but with low values (<6mm), again well below what was seen in the accident analyses. The impact angle only had a slight influence on the rib deflections.

The evaluations with the generic sled were extended to the human model developed by the Global Human Body Model Consortium (GHBMC). The simulations were limited to the APROSYS pulse only. Results of this work are available in Appendix III and further details can be found in the work of Hallbauer et al [12].

Pulse	Angle	Centre console structure
APROSYS pulse	90 deg & 75 deg	Rigid & none

The belt pretensioners were fired in all simulations

Where the centre console was present the lateral travel of the head, T4 and pelvis was reduced in both the 90 and 75 degree impacts when compared to no centre console. The reductions were small for the head (5-14%) and approximately 31-34% for the pelvis. As was the case for the WorldSID simulations, there was little difference in excursion between the two impact angles. A comparison of the kinematics between the GHBMC and WorldSID models indicated that the dummy model gave slightly more lateral and forwards excursion compared to the human body model. This lower excursion (70mm) can be explained by the stiffer spine in the WorldSID.

One final comparison made between the HBM and WorldSID models was the influence on the kinematics of the outboard elbow joint ‘hooking’ around the diagonal belt. The WorldSID was modelled with the standard half arm assembly only, whereas the HBM had full arms. Where the steering wheel was not modelled, the HBM showed there was hooking on the belt. The HBM simulation was repeated to allow the elbow to pass through the diagonal belt, which gave no difference in the lateral displacement of the head, T4 and pelvis when compared to when the elbow engaged with the belt. This aspect was highlighted as something that should be verified with the use of the WorldSID dummy.

PHYSICAL TESTING

Having established the boundary conditions with the use of accident data, it was then necessary to perform a series of tests to evaluate the feasibility of a sled based approach and to check the correlation between the physical tests and simulations. A supermini was chosen for the series. The vehicle had a low centre console and no far-side protection countermeasures. As the arm to belt interaction was highlighted as an area that should be examined during the physical testing, Transport Canada kindly provided Euro NCAP with the WorldSID full arm. The physical testing performed by the group consisted of two full-scale pole impacts and fourteen sled tests.

Full-scale pole tests

Two full-scale oblique pole tests were performed to establish the delta V for the vehicle and provide a comparison with the APROSYS pulse. The dummy positioning was in line with the Euro NCAP pole impact protocol, i.e. with a WorldSID on the driver’s seat, but the pole impacted the passenger’s side of the vehicle. The standard test speed of 32km/h resulted in a delta V of 38.8km/h. As this was below the target of 41km/h a second oblique pole test was performed at 36km/h giving a delta V of 42.4km/h. A higher test speed was not considered feasible due to the risk of structural failures in the vehicle body.

A comparison of the pulses from the chosen supermini are shown in Figure 9. The data provided is from the 32km/h and 36km/h tests along with APROSYS and the official Euro NCAP pulses recorded in the AE-MDB and oblique pole impacts.

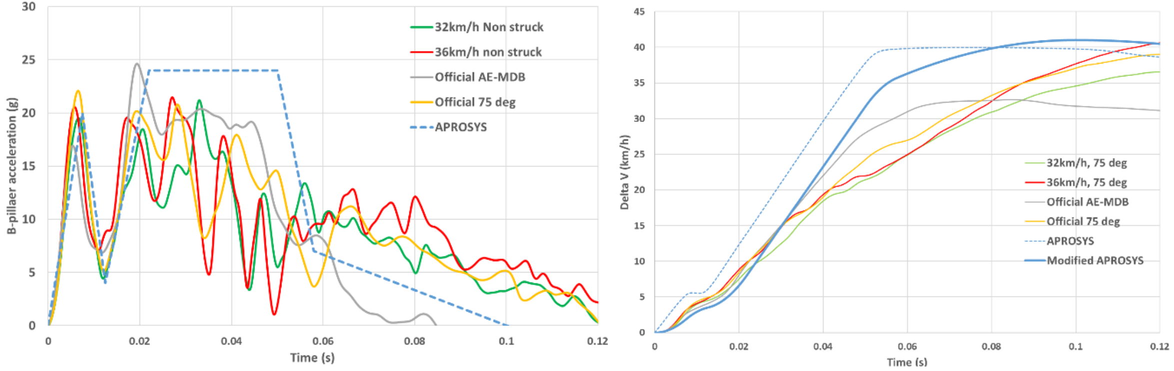


Figure 9: Supermini test vehicle pulses and delta V

The data from the 32km/h test showed all dummy outputs to be well below the WorldSID higher performance thresholds used in the Euro NCAP rating scheme. There was also no contact between the head and vehicle interior. In the 36km/h test, there were no structural issues with the bodyshell but there was a head contact with the far-side door (HIC3305), all other dummy outputs were below the higher performance thresholds, see Figure 10. The reason for the low torso outputs was a high level of rotation preventing the thoracic and abdominal ribs from being loaded in the expected manner. The rotation induced high loading in the neck and lumbar spine (forces and moments). This highlighted the need for both a kinematic and numerical assessment.

Figure 10: Oblique pole impact - 36km/h

Sled tests

Following the full-scale tests, two series of sled tests were performed. The sled tests were to be performed with the APROSYS pulse, which was chosen instead of the vehicle pulse because the intention was to examine the feasibility of the test procedure and not to perform an assessment of the vehicle. However, upon closer examination of the APROSYS pulse, it was discovered that the pulse did not have a delta V of 41km/h, the calculated value being 42.7km/h. As a result, the pulse was modified to match the target delta V of 41km/h. The initial peak of the pulse at 10ms was reduced from 20g to 14g to be more representative of the average peak seen in recent Euro NCAP AE-MDB tests on superminis. The plateau of the peak was also reduced from 24.0g to 23.8g to achieve the target delta V of 41km/h. For the purposes of this paper, this new pulse is termed the ‘modified APROSYS’ pulse and was used in the sled testing along with the 32km/h and 36km/h pulses.

A comparison of pulse and delta V from APROSYS, six superminis in AE-MDB impacts and the average fleet of vehicles assessed by Euro NCAP in 2015 is shown in Figure 11. The pulse is shown on the primary y-axis and delta V on the secondary y-axis.

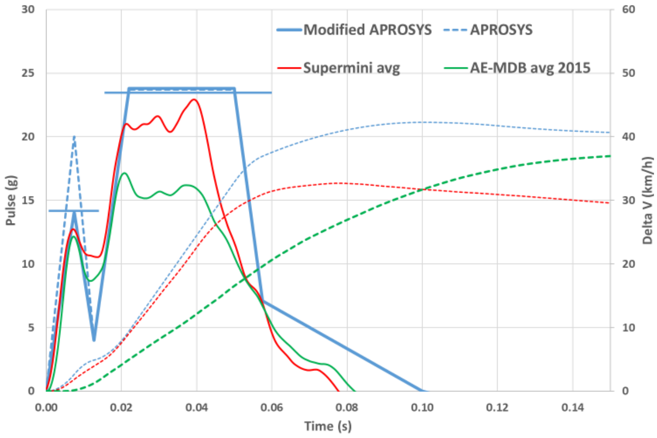


Figure 11: Pulse and delta V comparison

Test set-up for series 1

Based on the findings of the of the aforementioned publications and discussion of the various practical considerations with sled-based testing, a simplified setup was chosen for the sled tests as follows:

- Vehicle body in white
- No representation of struck-side intruding structures. Simulations showed that peak intrusion occurred before peak head excursion and a static marking would be sufficient.

- Body in white mounted at 75 degrees
- Modified APROSYS pulse & vehicle specific pulses
- One WorldSID 50th male driver, sleeved suit, in the standard pole impact seating position
- Full standard facia assembly including centre tunnel trim
- All first row seats
- The belt pretensioner was not fired in any of the tests as this would not occur in a far-side impact on the road with the vehicle chosen

Lines were marked on the buck to offer a comparison of head excursion. The blue line was placed on the vehicle centreline, yellow line on the struck-side seat centreline and the red line was marked at the location of the maximum static intrusion of the interior trim observed in the 32km/h pole or AE-MDB impact, see Figure 12.

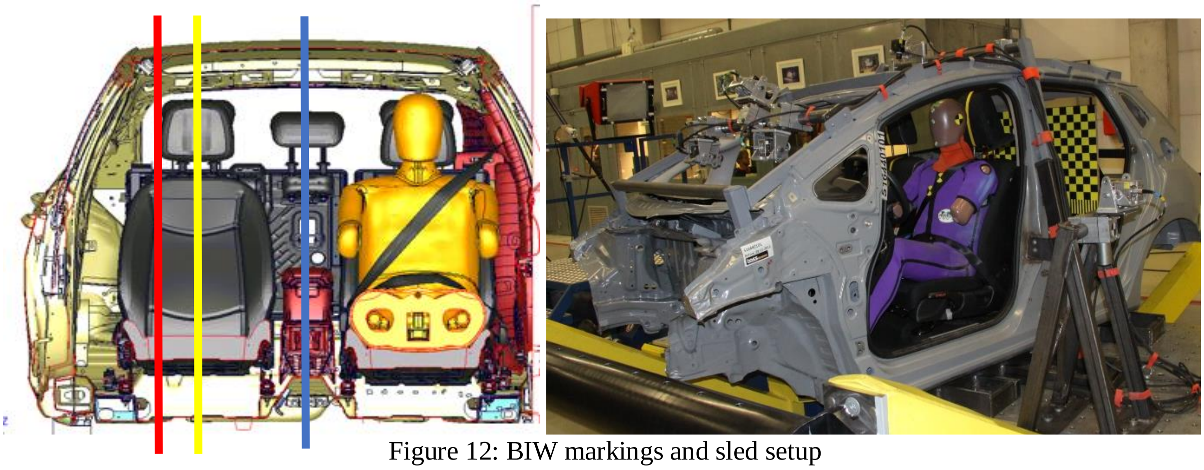


Figure 12: BIW markings and sled setup

Sled test series 1
Repeatability tests

The test matrix detailing the test numbers referenced in this report can be found in Appendix IV. Please note that the test numbers in the images differ from those in the test matrix. The first three sled tests were aimed at establishing repeatability of the sled and dummy setup, tests #1, #2 and #3. The struck-side airbags were fired only in the first test to identify any interaction with the dummy. As no interaction was observed, these airbags were not fired for the remaining sled tests. However, there was a difference observed in the seat kinematics due to the deployment of the side airbag in the first test filling the gap between the seat and vehicle structure.

The peak head excursion in the first test was approximately 50mm lower than of the other two tests and approximately 9ms earlier. This was caused by interaction between the WorldSID shoulder/jacket (with sleeves) and seatbelt, see Figure 13 and Figure 14. The belt slid into the gap between the shoulder and arm for a longer amount of time in the first test and subsequently increased the level of restraint up to the point where the belt began to slide down the dummy arm. It was found that the shoulder pad was incorrectly positioned in the shoulder rib prior to test. However, this interaction occurred in a number of the tests to a greater or lesser extent and was not considered top have influenced the results. In the third test, the interaction was such that the zip on the jacket was pulled open.

It was thought that the interaction would be reduced with the use of the sleeveless WorldSID suit and triggering of the seat belt pretensioner. The sleeveless suit was already implemented in the Euro NCAP AE-MDB and pole tests.

The full table of dummy outputs can be found in Appendix V. The dummy head and shoulder values were comparable and below the existing AE-MDB higher performance limits (HPL). In test #1, where the belt interaction was greatest, the thoracic rib deflections (TR) were all relatively low. In test #2 and #3, only one rib was close to the higher performance limit. In test #2, this was TR2 and in test #3 TR3, the difference being dependent on how the dummy was aligned with the loading structures (belt and/or centre console). All other dummy parameters were comparable and well below the HPL.

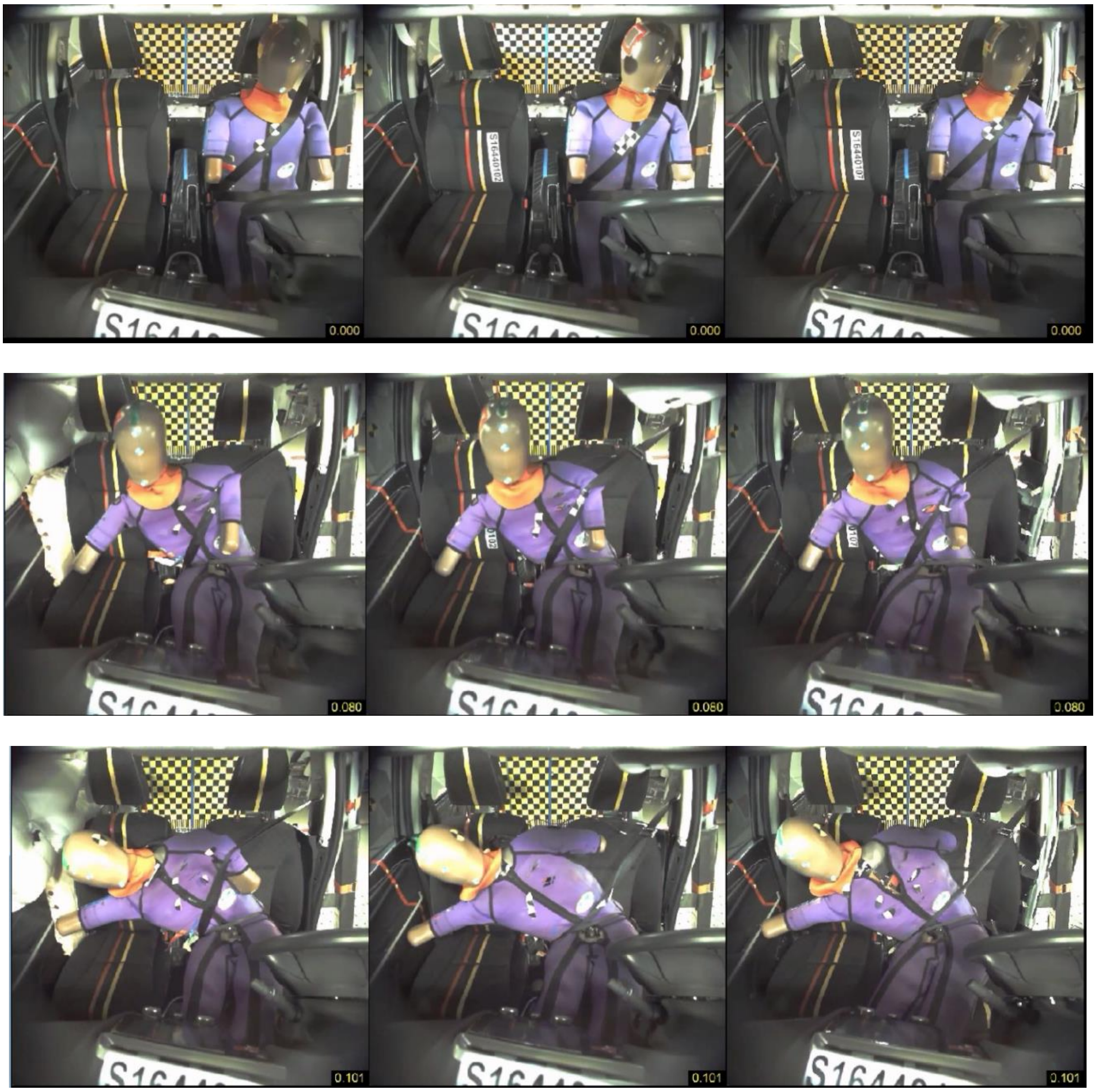

Test #1 Test #2 Test #3

Figure 13: Repeatability test - belt interaction

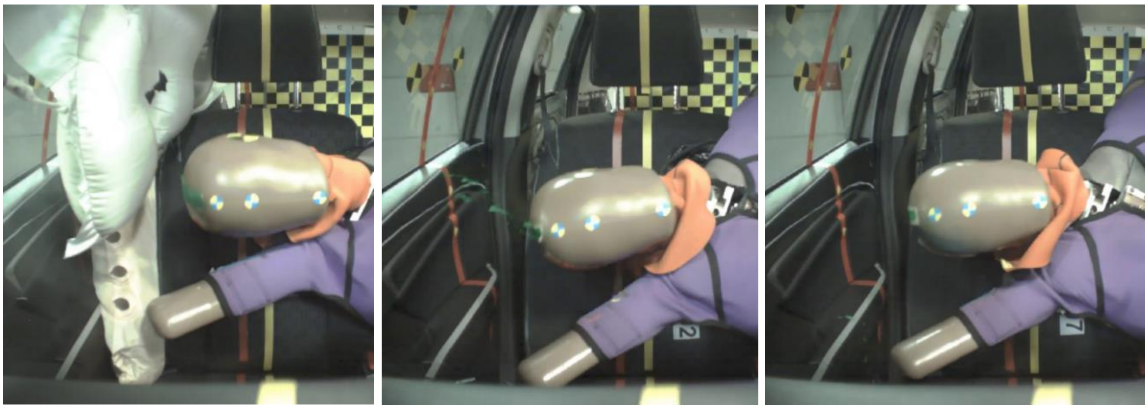

Test #1 Test #2 Test #3

Figure 14: Repeatability test - max head excursion

WorldSID full arm, test #4

The second of the repeatability tests (#2) was chosen as the best baseline scenario for comparison with other tests due to the least amount of shoulder/belt interaction. A test was performed with the prototype full arm assembly attached to the driver's outboard arm, #4. It was used to provide a comparison with the HBM simulations that suggested the elbow hooking on the diagonal belt would not have a significant influence on the results. Having observed the shoulder to belt interaction in the first tests, the full arm tests were subsequently performed with a modified shoulder pad from the THOR dummy to limit the likelihood of the belt sliding into the shoulder gap. The full arm assembly and shoulder pad are shown in Figure 15.

Although the addition of the shoulder pad prevented the belt from interacting with the shoulder, the belt was caught by the top of the bicep resulting in a higher level of restraint than occurred with the half arm assembly. The bicep of the full arm has a flat upper surface and is of a different shape to that of the half arm assembly. This led to approximately 40mm less excursion with the full arm, see Figure 16. The torso and pelvis were unaffected by the different engagement. It was suspected that the arm hooked on the shoulder belt but a direct comparison of the kinematics with the HBM simulations could not be made due to the different belt interaction. Given the status and availability of the full arm, implementation into a test protocol was not realistic. The full arm was subsequently given no further consideration for use the test protocol. The dummy outputs are detailed Appendix V, but this part of the work focussed on the kinematic differences observed with the full arm.

Figure 15: WorldSID full arm and THOR shoulder pad

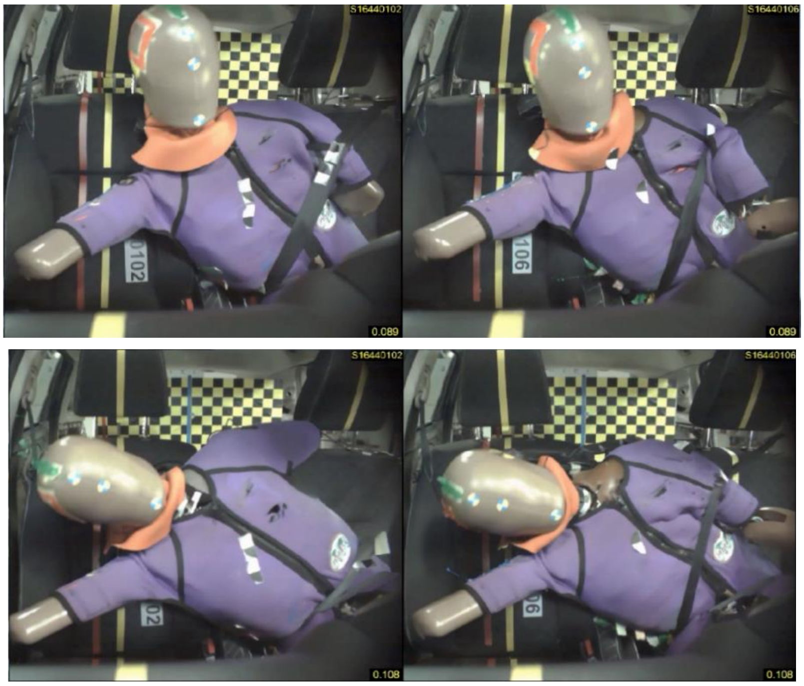

Test #2 Test #4

Figure 16: Half arm and full arm belt interaction - max excursion

Large centre console, test #5

Previous research indicated that the WorldSID might be suitable for use in far-side impacts [1]. A test was performed with a high centre console to see how well the dummy could detect the presence of such structures. A structure was fabricated out of stiff foam covered with sheet metal that was 180mm above the dummy H-point and approximately 60mm taller than the standard console. As expected, the presence of the large center console reduced the lateral head excursion by approximately 115mm, but also resulted in 42% greater neck My loading. The additional neck loading was caused by further rotation of the head. The outboard arm rotated rearwards around its fixing and contacted the head after the time of peak excursion. Although this was not detrimental to the kinematics or dummy outputs, the performance was not biofidelic. The torso loading was focused on the abdominal ribs (AR): AR 1, 46mm and AR2, 31mm, posing an additional risk of abdominal injury. The test with the standard console had maximum loading in the thoracic ribs, (TR): TR2 28mm and TR3 14mm. See Figure 17.


Test #2 Test #5

Figure 17: With and without centre console max excursion

Vehicle pulse tests #6 & #7
Two sled tests were performed with vehicle specific pulses (#6 & #7) obtained from the two full-scale pole tests at 36km/h and 32km/h. Tests #6 and #7 were compared with the modified APROSYS pulse (#2). The characteristics of the pulses and delta V is shown in Figure 9. Although the delta V of the 36km/h test was similar to that of the modified APROSYS pulse (41km/h), the profile was different.

When comparing the 36km/h pulse (#6) with the modified APROSYS pulse (#2), the more severe modified pulse between 25ms and 120ms led to an earlier max head excursion (118ms vs 135ms). However, the maximum excursion was approximately 20mm greater with the vehicle pulse. The thoracic rib loading was higher in the 36km/h pulse compared to the modified pulse, whereas the abdominal ribs were higher in the modified pulse. However, the only limit that was exceeded was TR3 in the 36km/h pulse, being 128% of the HPL. See Figure 18.

The pulse characteristic of the modified APROSYS pulse (#2) was significantly different to that of the 32km/h vehicle pulse (#7), with a delta V of 41km/h vs 38km/h. As mentioned above, the initial phase of the test influenced the dummy kinematics in a similar way. Due to the lower severity, the head excursion in the 32km/h tests was 20mm below that of the modified pulse. None of the HPL were exceeded in the 32km/h test.

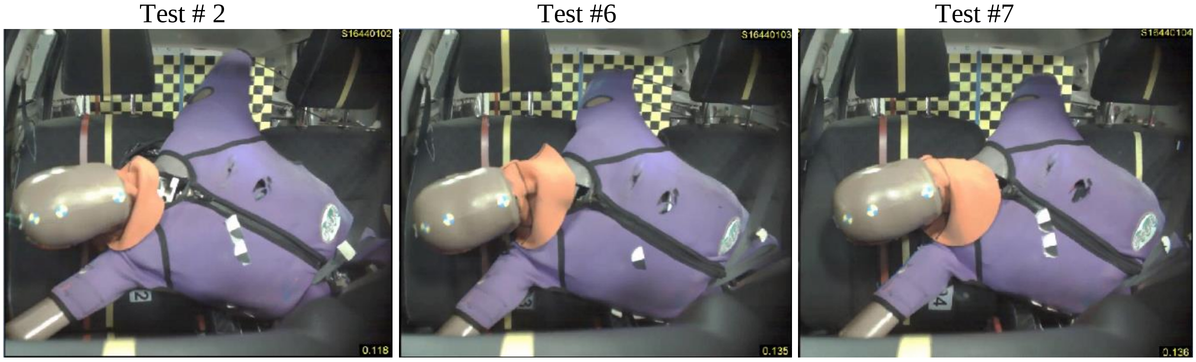

Test # 2 Test #6 Test #7

Figure 18: Modified APROSYS pulse vs 36km/h pulse vs 32km/h pulse - max head excursion

Comparing the tests using the two vehicle specific pulses (#6 & #7) shows a higher head excursion in the 36km/h pulse of approximately 40mm. This was to be expected given the higher delta V. The dummy thoracic loading showed a slight difference between these tests; in test #7 TR2 was highest, whereas in test #6, TR3 was highest. There was visibly more bending of the torso in test #6. Only the compression from TR3 in test #6 exceeded the HPL (128%). The abdominal loadings were all below 33% of the HPL. It is worth reaffirming that the intrusion line in both of these tests was based on the 32km/h test; in a 36km/h impact there would be approximately 70mm of additional intrusion.

The final comparison made was between the two vehicle specific sled pulses and the respective full-scale pole test. Unfortunately, the onboard cameras on the 32km/h full-scale pole tests failed so no detailed comparison of the dummy kinematics could be made. As there was no intrusion simulated in the sled tests, the kinematics differed to those of the full-scale test after the head contacted the intruding door in the full-scale test at 36km/h, see Figure 19. The head acceleration trace shows that although the curtain airbag deployed in the full-scale tests, it was not able to prevent the head from contacting the top of the door panel at approximately 115ms. Up to that point, there were only slight kinematic differences found in the head rotation between the full-scale and sled tests. There was no head contact with the intruding door in the 32km/h test. Replication of the pole intrusion was out of the test scope for this first series of testing. As the intention was to evaluate the feasibility of a sled procedure, reproducing intrusion was considered an unnecessary complication.

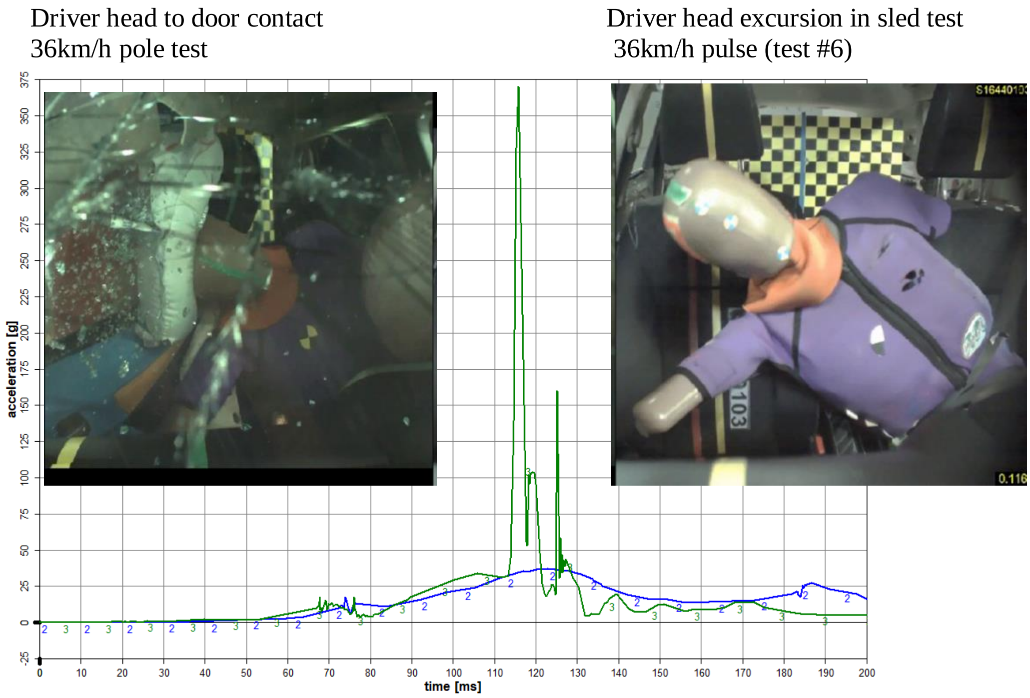


Figure 19: Driver head resultant accelerations - sled and full-scale test comparison

Summary of sled test series 1

In the full-scale tests the deploying struck-side airbag bridged the gap between the seat and intruding vehicle structure. This bridging effect was not replicated in the first series of tests, but it was thought that supporting the seat with foam spacers would offer a simplified way of simulating the presence of the airbag.

The influence of the full arm was not considered significant enough to require the full arm to be used in all sled tests. The THOR shoulder pad could not prevent belt interaction with the upper arm and a subsequent reduction in head excursion. Unfortunately, the effect of the elbow hooking on the diagonal belt could not be fully established or compared directly with the HBM data due to an incorrect test setup.

The baseline tests (#1, #2 & #3) were all influenced by shoulder to belt interaction. The greater the interaction, the smaller the excursion and the spread of max head excursion was approximately 80mm across the three tests. It was thought that this interaction could be reduced with the use of the sleeveless suit and the deployment of the belt pretensioner.

The fabrication of a large centre console resulted in head to arm contact and increased neck loading. The arm kinematics were not representative of a human. The large centre console did reduce lateral excursion by approximately 115mm, although it introduced an additional risk of abdominal injury. However, none of the HPL were exceeded.

Three different pulses were used in the first test series: 32km/h and 36km/h vehicle specific pole impact pulses and the generic modified APROSYS pulse. The 36km/h pulse and modified pulse had a similar delta V of approximately 41km/h and the 32km/h pulse had a delta V of approximately 37km/h. Delta V was not the only factor influencing occupant kinematics, the shape and duration of the pulses also having a significant effect.

Almost all of the dummy outputs resulted in readings below the established higher performance limits. The head excursion in all tests was beyond the (red) intrusion line and the seat centreline.

Sled test series 2

The outcome of the first seven sled tests was used to plan the second series of seven sled test series. Again, the modified APROSYS pulse was used along with the vehicle specific pulses. The test matrix detailing the variables is in Appendix VI and a table of dummy outputs can be found in Appendix VII. It should be noted that the camera locations differ slightly between the two series of tests and the lines superimposed on the images differ from the seat centreline due to movement of the seat during the tests.

The considerations for the second series tests were:

Sleeveless suit (all series 2 tests)
Belt pretensioning
Near-side seat support
Large centre console
Spacers between seat and vehicle structure

Sleeveless suit, test #8

The first test performed in series 2 (test #8) was a repetition of the repeatability tests with the use of the sleeveless WorldSID suit, test #1. There was no interaction between the belt and sleeveless suit, the more close fitting sleeveless suit had less material which prevented the bunching of material that was observed with the sleeved suit, see Figure 20. The maximum head excursion was approximately 80mm greater with the sleeveless suit.

Test #1 Test #8

Figure 20: Sleeved vs sleeveless WorldSID suit – belt to shoulder interaction

Pretensioners, test #9

Test #9 was similar to that of test #8 but the belt pretensioner was fired. Unfortunately, the analysis of the pretensioner effects was hindered by a different arm adjustment and a different upper belt anchorage position prior to test. In test #9, the arms were set closer to the torso and the belt anchorage lower than in test #8. The lower anchorage increased the shoulder rearward movement up to 50ms and resulted in less interaction with the arm below the shoulder joint, see Figure 21. The pretensioning limited the rotation of the torso and pelvis, leading to a shift from the even TR2/TR3 load distribution of test #8 to a higher load on TR2.

Test #8 Test #9

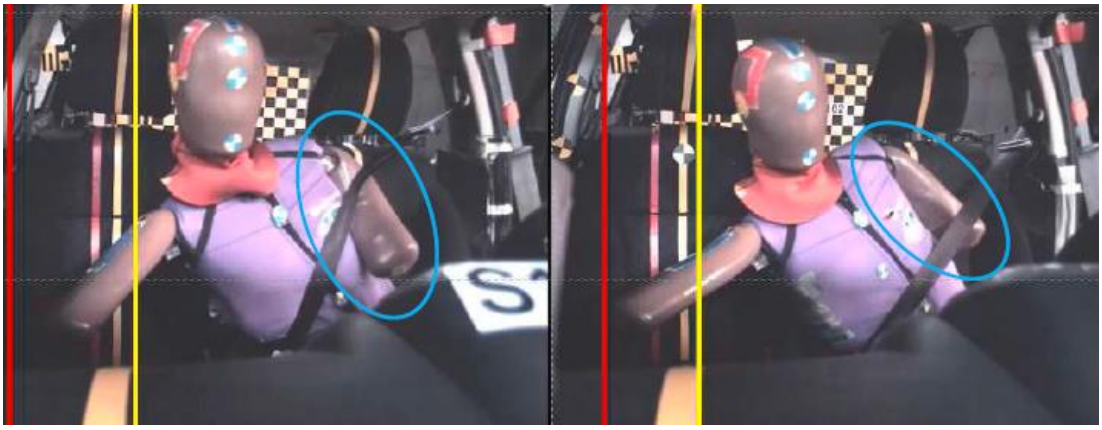


Figure 21: With and without pretensioning – belt to arm interaction

Spacers, test #10

The movement of the seats due to airbag deployment and, in the real-world, intrusion was identified in series 1. The seat was seen to move inboard, bridging the gap to the centre console. In order to replicate this, a test (#10) was performed with stiff foam spacers bridging the gaps on both sides of the unoccupied seat. The belt pretensioner was fired meaning a comparison with test #9 was necessary. Bearing in mind the incorrect setting of the dummy arms and belt anchorage in test #9, a comparison was made of tests with and without spacers. There was slightly more torso rotation without the spacers (with higher belt anchorage position) but only a small difference in max head excursion (20mm). The neck loading was uninfluenced but there were slightly higher lumbar moments (Mx) and lower torso rotation. It was thought that the spacers supported the centre console as it was loaded by the dummy.

Test #9 Test #10

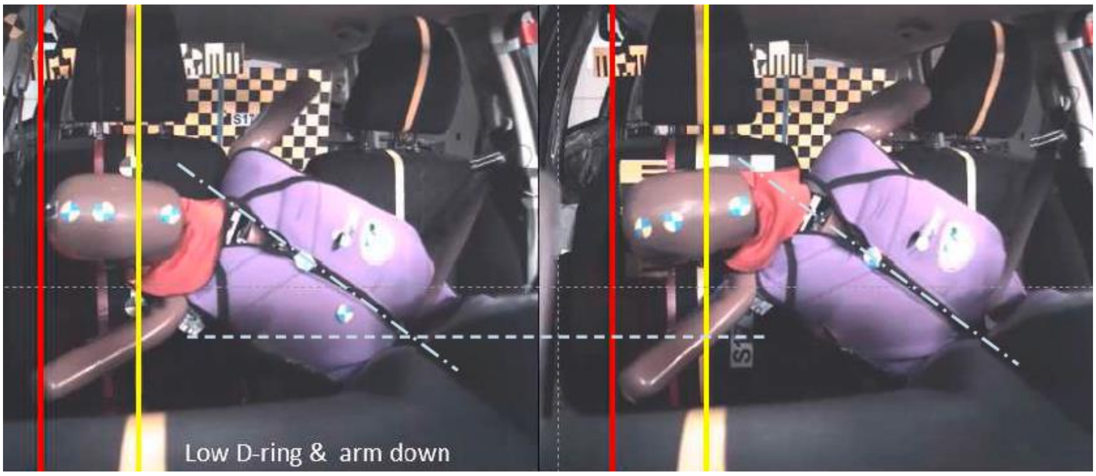


Figure 22: With and without spacers – max head excursion

Pretensioning and spacers, test #8 & #10

A comparison of test #8 and #10 was made to examine the influence of pretensioning and spacers. Without the spacers the centre console was seen to move laterally from about 42ms. With pretensioning and the addition of the spacers the max head excursion was reduced by approximately 20mm. The rib loading shifted from TR2 and TR3, to TR3 with AR2 loading significantly reduced, lumbar My increased by about 44%.

Test #8 Test #10

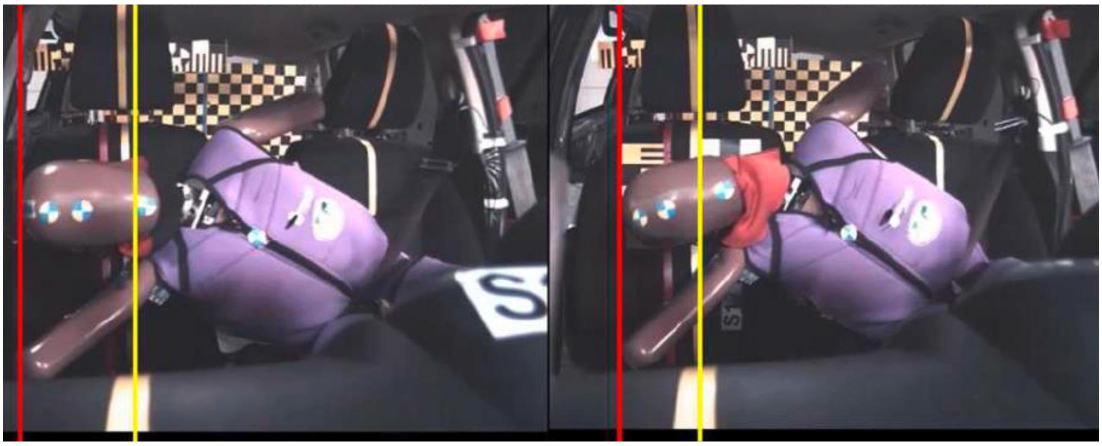


Figure 23: With and without pretension and spacers – max head excursion

Large centre console, test #11

As was the case in series 1, the presence of a large centre console was examined. The outcome was similar to that of the first series where the lateral head excursion was reduced and the abdominal rib loading increased, but still below the higher performance criteria, See Figure 24.

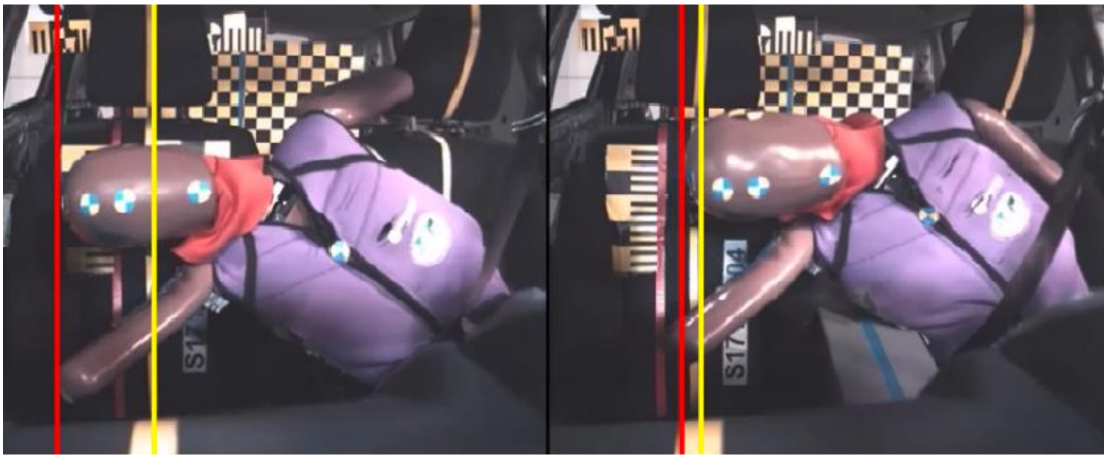

Test #10 Test #11

Figure 24: With and without large console – max head excursion

The presence of the centre console was compared between the test from series 1 (no pretensioning and sleeved suit) and series 2 (with pretensioning and spacers). The dummy outputs were very similar as was the max head excursion. See Figure 25.


Test #5 Test #11

Figure 25: With and without sleeveless suit pretension and spacers – max head excursion

Pretensioning, spacers and jacket

The pretensioning, spacer and jacket effects were compared using the vehicle specific pulses at 32km/h (Figure 26) and 36km/h (Figure 27). These comparisons gave similar results to those above (#8 and #10) with the modified APROSYS pulse. There was slightly lower lateral head excursion and some Z axis rotation in the test with pretensioning, spacers and sleeveless suit. There was no significant influence on the dummy outputs. The greatest head excursion and dummy outputs were seen in the 36km/h tests followed by the modified APROSYS pulse and then the 32km/h pulse.


Test #7 Test #12

Figure 26: With and without sleeveless suit pretension and spacers – max head excursion


Test #6 Test #14

Figure 27: With and without sleeveless suit pretension and spacers – max head excursion

Vehicle specific pulses, #12, #13 & #14
The presence of the large centre console was evaluated with the vehicle specific 32km/h pulse. The findings of this comparison were similar to those of the previous comparison with tests #10 and #11 that used the modified APROSYS pulse, see Figure 28.

The final comparison was between the two vehicle specific pulses at 32km/h and 36km/h. As expected, the higher pulse gave more lateral head excursion (50mm) and a shift of loading from the TR2 to TR3. The other dummy outputs were comparable.

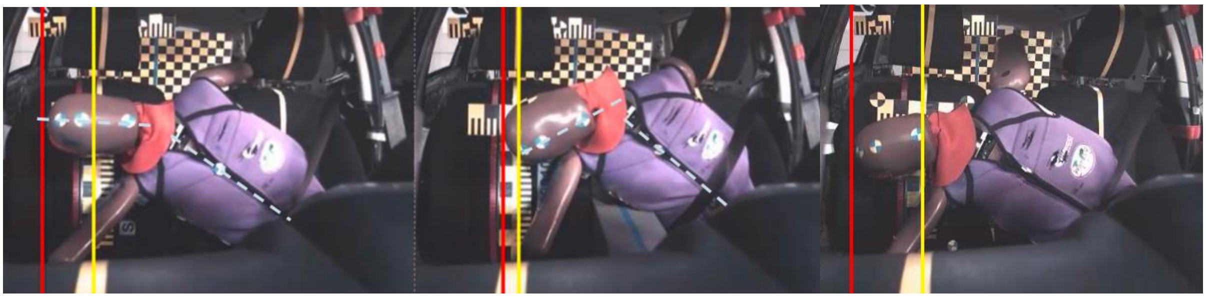

Test #12 Test #13 Test #14

Figure 28: With and without large console

Summary of series 2

One of the major issues highlighted in series 1 was the interaction between the shoulder belt and sleeved WorldSID dummy jacket. This interaction was successfully reduced by the adoption of the sleeveless jacket and pretensioning of the belt. There were no instances of shoulder to belt interaction observed in series 2.

The effect of ‘spacers’ between the B-pillar, seat and centre console was examined. Spacers were added to replicate the effects of intrusion during an impact that closes the gap between the vehicle and seat. This was achieved in the undeformed sled setup, albeit in a simplified manner, by fitting rigid foam blocks to support the seat frame with the surrounding structures. The dummy outputs were seen to increase slightly in the neck and lumbar body regions, but it was thought that the effect of deformation must be represented in vehicle between the struck-side seat and BIW. The spacers also help to limit the movement of the centre console. It was not necessary to trigger seat mounted side airbags as their influence on bridging the gap between the vehicle and seat would be represented by the spacers. In the event that there is a far-side occupant countermeasure, e.g. larger side airbags, then this can be accommodated by the test procedure.

The modified APROSYS pulse and 36km/h pole impact pulses had similar delta Vs, both higher than that of the 32km/h pulse. However, it was not just a higher delta V that resulted in greater head excursion and dummy readings. The shape of the pulse can also determine the amount of dummy loading. The dummy readings from the modified APROSYS test were higher than both of the vehicle specific pulses, for which the results were similar.

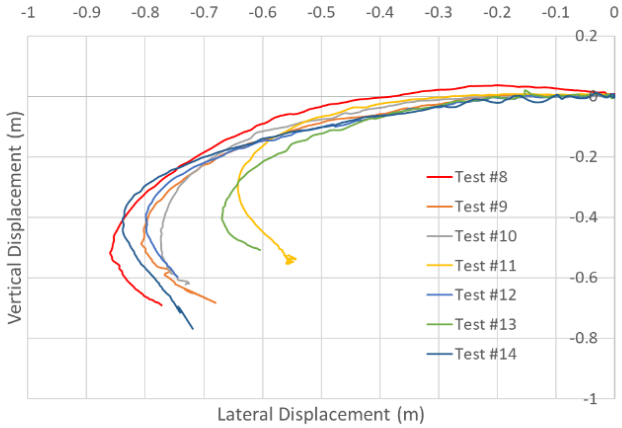


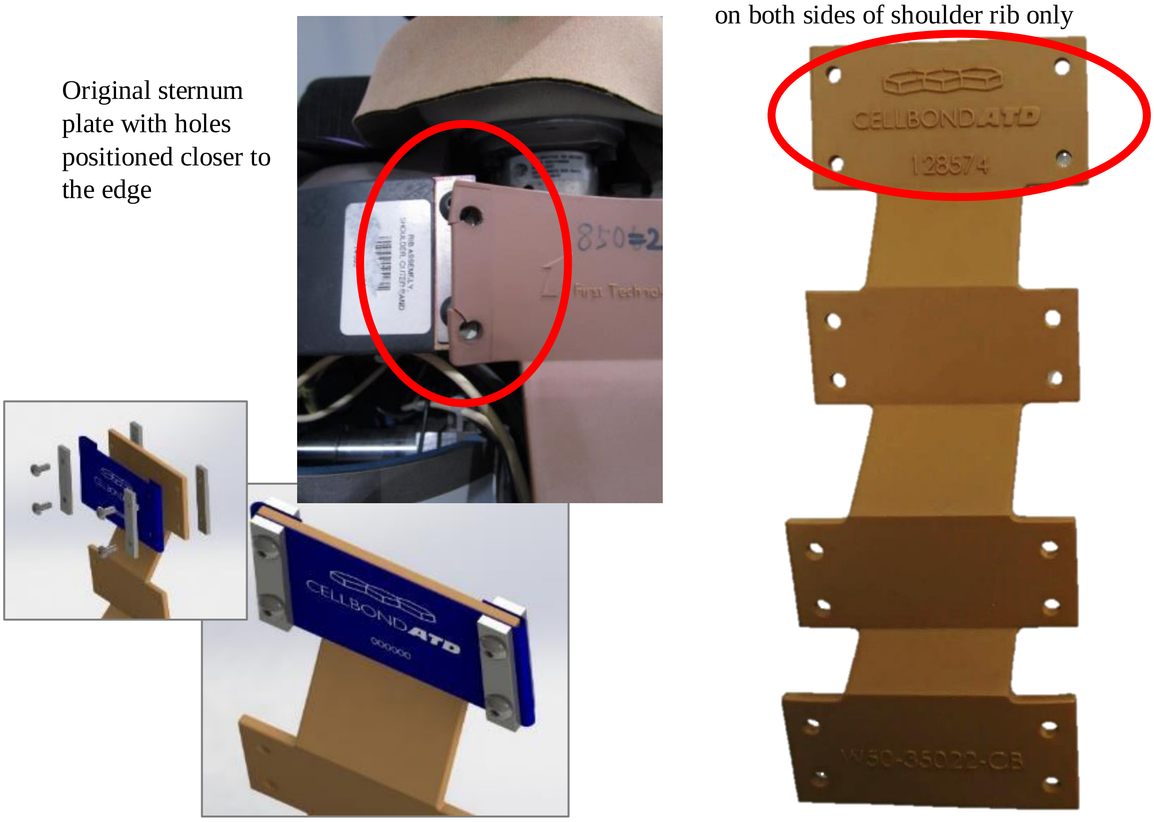
Figure 29: Series 2 head top film tracking

The greatest influence on the lateral head (top) excursion was due to the presence of the large centre console, which was present in tests #11 & #13. This reduced the excursion in these two tests to approximately 0.65m, whereas the excursion in all other tests (with standard centre console) was 0.77m to 0.86m. See Figure 29.

DUMMY DURABILITY ISSUES

One of the first issues highlighted in the sled tests was the WorldSID jacket being cut above the outboard abdominal ribs. As the dummy moved inboard and slid beneath the seatbelt, the upper edge of the first thoracic rib cut through the suit. The damage to the jacket did not influence results in any of the sled tests. Solutions to this damage were discussed with a dummy manufacturer. Enlarged and reinforced Kevlar patches on the inside and outside of the jacket were thought capable of preventing such suit damage.

Under certain conditions, the sternum plate holes have been known to tear at the shoulder rib connection. It is assumed that this component was originally designed for compression loading only (near-side testing) and the far-side testing subjects it to tensile loading. The holes for the shoulder rib, the only area where damage has been found, were closer to the material edge than the other ribs, increasing the likelihood of failure. A modified sternum plate has been developed with additional material outboard of the holes along with a fabric overlay, either as additional strengthening or an interim solution, that strengthens the sternum plate holes under tensile loading but has no influence on the compressive stiffness. It is believed that this issue has been presented to the ISO group. See Figure 30.



Updated design with additional material on both sides of shoulder rib only

Original sternum plate with holes positioned closer to the edge

Figure 30: Sternum modifications

The WorldSID arm kinematics observed in some of the tests was not biofidelic. The use of the full arm was not thought necessary and, given the prototype status, cannot be implemented in the far-side procedure in the foreseeable future. It was necessary to continue drafting the procedure with the half arm assembly, even though its biofidelity is limited. Care should also be taken to ensure that ATDs with umbilicals have their cables routed in a way that does not influence the movement of the dummy and limits interaction between the cables and vehicle interior.

The far-side testing appears to be applying greater loads to the WorldSID lumbar spine than the near-side testing. An investigation by JAMA highlighted an incidence where the lumbar spine mount contacted the abdominal rib, resulting in a spike in the lumbar traces. The abdominal rib has also been known to contact the pelvis flesh. It should be noted that no such occurrences were identified in the SIWG tests or the 2018 assessments from Euro NCAP. The lumbar rubber is not a certified component and may not lend itself to a reliable certification test. At this stage, it is questionable as to how much of an influence this may have on the head excursion, particularly where a vehicle offers good control of the dummy kinematics by limiting the inboard movement. The relevance and need for a test will be examined in the future along with how such a corridor might be established.

ASSESSMENT CRITERIA

Euro NCAP has highlighted the protection of far-side occupants as an area of vehicle design that should be improved. The objective of the assessment is to reward vehicles that offer control of occupant kinematics, thus limiting head and torso excursion and reducing the risk of contacts with the struck-side interior and other occupants. Euro NCAP would like to encourage countermeasures that have been specifically designed for far-side impact scenarios which would prevent occupant to occupant contact while also ensuring that there are no additional risks presented to the occupants. The assessment of far-side protection focuses on two areas, dummy head excursion and evaluation of the dummy outputs. The accident data indicated that reduced lateral excursion of the occupant potentially reduces interaction with the vehicle and subsequently reduces the risk of injury not just to the head, but also the torso [8] [9].

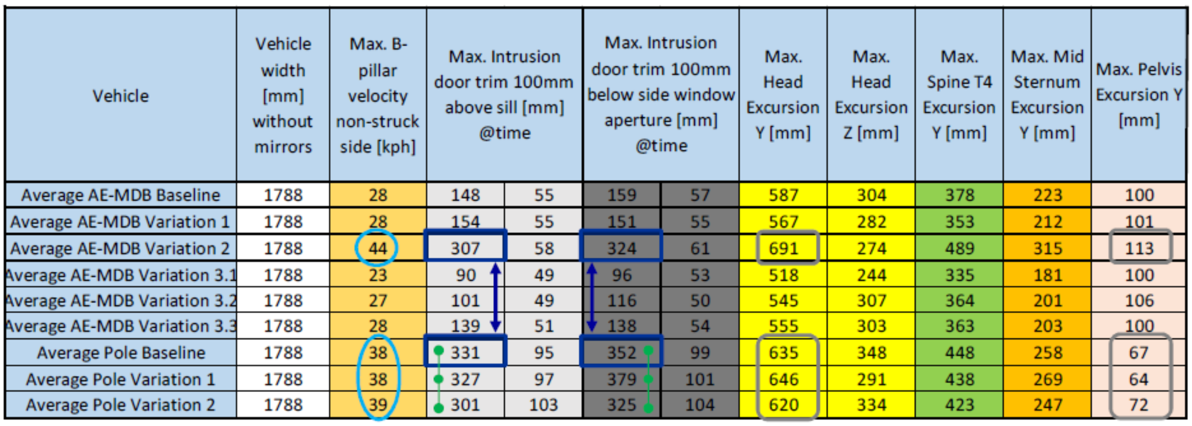
Excursion lines were established at the location of peak vehicle intrusion and the seat centreline. The position of the intrusion line would be based upon that seen in the official Euro NCAP test, or an equivalent in-house test if testing is performed early in the vehicle development. Where an in-house test is used, the pulses and intrusion will be cross checked with the official Euro NCAP tests. The intrusion is measured at the most inboard point of the vehicle interior. As mentioned previously, peak intrusion occurs before the maximum head excursion, so there was no need to reproduce the dynamic intrusion in the test procedure, see Table 1.

An occupant to occupant interaction limit was specified at the inboard edge of the far-side seat. This area of interaction was identified in a series of numerical simulations performed by ACEA, AE-MDB tests with two occupants showed head to shoulder contact in this region. The simulation showed there was significantly more rebound of the driver in the pole impact scenario compared to the AE-MDB.

The simulations were performed with the WorldSID model and were based on a number of the vehicles tested by Euro NCAP in 2015. The head contacts were mostly on the door trim (armrest) and therefore too low to be covered by the curtain airbag.

- 2 Small family cars
- 1 Supermini
- 1 Large Family Car
- 2 Small MPVs

Table 1: Vehicle simulations



Vehicle	Vehicle width [mm] without mirrors	Max. B-pillar velocity non-struck side [kph]	Max. Intrusion door trim 100mm above sill [mm] @time		Max. Intrusion door trim 100mm below side window aperture [mm] @time		Max. Head Excursion Y [mm]	Max. Head Excursion Z [mm]	Max. Spine T4 Excursion Y [mm]	Max. Mid Sternum Excursion Y [mm]	Max. Pelvis Excursion Y [mm]
Average AE-MDB Baseline	1788	28	148	55	159	57	587	304	378	223	100
Average AE-MDB Variation 1	1788	28	154	55	151	55	567	282	353	212	101
Average AE-MDB Variation 2	1788	44	307	58	324	61	691	274	489	315	113
Average AE-MDB Variation 3.1	1788	23	90	49	96	53	518	244	335	181	100
Average AE-MDB Variation 3.2	1788	27	101	49	116	50	545	307	364	201	106
Average AE-MDB Variation 3.3	1788	28	139	51	138	54	555	303	363	203	100
Average Pole Baseline	1788	38	331	95	352	99	635	348	448	258	67
Average Pole Variation 1	1788	38	327	97	379	101	646	291	438	269	64
Average Pole Variation 2	1788	39	301	103	325	104	620	334	423	247	72

The other part of the far-side assessment is dummy criteria. Existing criteria were adopted where possible, e.g. the head, rib compression, pubic symphysis etc, but additional criteria were also included. Some criteria for brain injury risk are also being monitored for possible future adoption. The thoracic rib compression limit of 28mm is based on the skeletal risk, whereas abdominal rib compression (47mm) is based on the soft tissue risk. Nevertheless, even with the presence of a large, ‘rigid’ centre console the maximum abdominal rib compression in the two series of tests was 45mm.

The accident data showed cases of cervical spine injury, Forman et al [10]. GIDAS data also showed that impacts with a lower delta V (16 & 34km/h) than the target of 41km/h can result in C2 vertebrae fractures (AIS 3). Unfortunately, biomechanical criteria for the neck and lumbar regions is limited, so the decision was taken to specify pragmatic limits that prevent unreasonably high values. As there is no WorldSID transfer function for neck tension (Fz) and little reliable data for moments, the limits were adopted as pass/fail criteria only. This was also the case for the lumbar, where data showed disc breaking in the region of 2.84kN [11].

A rating was developed based upon three body regions with four points being awarded to each body region, a maximum of 12 points is available for each impact scenario, see Table 2. A penalty is applied to the overall score of a test where the lumbar loads exceed the prescribed limit. The head excursion assessment is then applied to the dummy score of each scenario. Where the head passes the seat centreline, zero points are awarded for the head, and if it passes the intrusion line, no points will be awarded for that scenario. Finally, where the occupant interaction line is passed, the score for that scenario will be halved. The scores for each scenario are then combined and scaled down from 24 points to four.

Further details of the assessment are contained in the Euro NCAP Far-Side Test and Assessment Protocol v1.1.

Table 2: Assessment criteria

	Criteria	**Performance limits**			**Points**
		Higher	**Lower**	**Capping**	
Head	HIC_{15} (with hard contact)	500	700	700	4 points
	Resultant 3ms acceleration	72g	80g	80g	
	SUFEHM/BrIC	monitoring			
Neck	Tension Fz		3.74kN		4 points
	Lateral flexion MxOC		50Nm		
	Extension negative MyOC		50Nm		
Chest & Abdomen	Chest lateral compression	28mm	50mm	50mm	4 points
	Abdomen lateral compression	47mm	65mm	65mm	
Pelvis & Lumbar	Pubic symphysis	2.8kN			-4 points
	Lumbar Fy	2.0kN			
	Lumbar Fz	2.84kN			
	Lumbar Mx	100Nm			

2018 RESULTS

It was initially planned for the far-side assessment to be implemented in 2018. However, as the development of the procedure took longer than anticipated this was delayed until 2020. A draft protocol was made available in 2017, with 2018 and 2019 designated as a period of monitoring and protocol 'fine tuning'. During the monitoring phase, far-side data was required by Euro NCAP but not considered in the vehicle rating.

In 2018, a total of 20 vehicles were assessed by Euro NCAP and it is worth noting that none of these vehicles were superminis. Vehicle manufacturers provided sled data with vehicle specific pulses for AE-MDB (60km/h) and oblique pole impacts. Two vehicles were not equipped with side curtain airbags and were not subjected to the pole tests, so no far-side data was provided for these vehicles.

In all cases, the peak head excursion was beyond the occupant interaction limit. In four cases, the head exceeded the seat centreline; in a further three cases the head excursion exceeded the intrusion line. Head excursion was higher in the pole impact for 13 of the cars, and in the AE-MDB for three. In the remaining cases the excursion was so similar an accurate determination could not be made. In many cases, although the excursion was deemed highest in the pole test, there was not a large difference compared to that observed in the AE-MDB test. There were no hard contacts with any part of the vehicle interior or any notable interaction with the far-side seat, as was to be expected given that intrusion was not replicated.

In three of the tests the thoracic rib higher performance limit (28mm) was exceeded, all on the lower rib. One of these tests was the AE-MDB pulse and the remaining two were pole pulses, the largest value recorded being

31mm. The soft tissue abdominal rib HPL (47mm) was not exceeded in any of the tests. Application of the skeletal risk limit (28mm) would result in only three tests above this limit (max 31mm).

The neck Mx limit was exceeded in 12 tests; the My limit was exceeded in one test only. The lumbar Fz limit was exceeded in one test, Fz and Mz were exceeded in five and four of the tests respectively. As mentioned previously, biomechanical criteria for the neck and lumbar regions is limited, so pragmatic limits were set to prevent unreasonably high values. There was no correlation between exceeding the neck limits and head excursion, the lumbar Mx limit was only exceeded in cases where the head excursion approached the seat centreline.

Given the frequency of far-side injuries in accident data and the results of the monitoring phase, it appeared that the WorldSID may not be predicting thoracic or abdominal injury risk as originally anticipated. The assessment of head excursion would seem to offer the best evaluation of far-side occupant protection as the kinematics of the dummy are sufficiently representative of those of a human. Further consideration of the assessment limits will be made by the group in the future.

FUTURE WORK

Due to the limited capabilities of the WorldSID, the focus of the assessment must be on excursion of the head and torso. The working group is discussing ways to be more discriminative of the vehicles assessed and to ensure that the procedure encourages the fitment of countermeasures that reduce excursion and offer protection against occupant to occupant contact. At the time of writing, the details of this assessment are still to be finalised, but one possible option is with the use of an additional excursion line, see Figure 31. Proof of sufficient protection for vehicles with an occupant to occupant countermeasure is also under discussion. The current proposal is for a second WorldSID to be included in the official oblique pole impact to enable a demonstration of the efficacy of such countermeasures. The feasibility of such a test is still under consideration by the group.

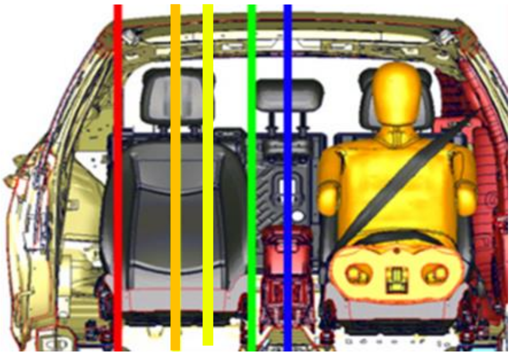


Figure 31: Draft assessment update

CONCLUSION

The development of the Euro NCAP far-side procedure began with accident data analyses. Previous accident research was combined with new analyses to establish the parameters that could be applied to a sled-based test procedure. In additional to the accident research, various numerical simulation studies were performed along with fourteen sled tests to investigate the factors affecting far-side protection.

The procedure aims to encourage vehicles to limit occupant excursion and mitigation of occupant to occupant interaction. A single ‘generic’ pulse was considered but this was found to be too limited given the variation in mass of the vehicle fleet and the increasing prevalence of electric vehicles. Two impact scenarios are therefore used to evaluate each vehicle model: a barrier to car impact and a pole impact, and both tests use vehicle-specific pulses. The sled setup is a simplified body in white that does not replicate struck-side intrusion as this was considered an unnecessary complication.

Results from the 2018 monitoring phase show that the WorldSID dummy has limited capability in predicting thoracic and abdominal injury risk. None of the dummy outputs exceeded the established injury criteria. However, in a number of cases the pragmatic neck and lumbar spine limits were exceeded. The kinematic assessment is appropriate and a simple method for assessing the head excursion has been adopted. This method is still under discussion and subject to change in favour of a more discriminating method. The far-side assessment will become part of the Euro NCAP rating from 2020. At the time of writing, the latest version of the procedure is version 1.1, November 2018 and is available at www.euroncap.com.

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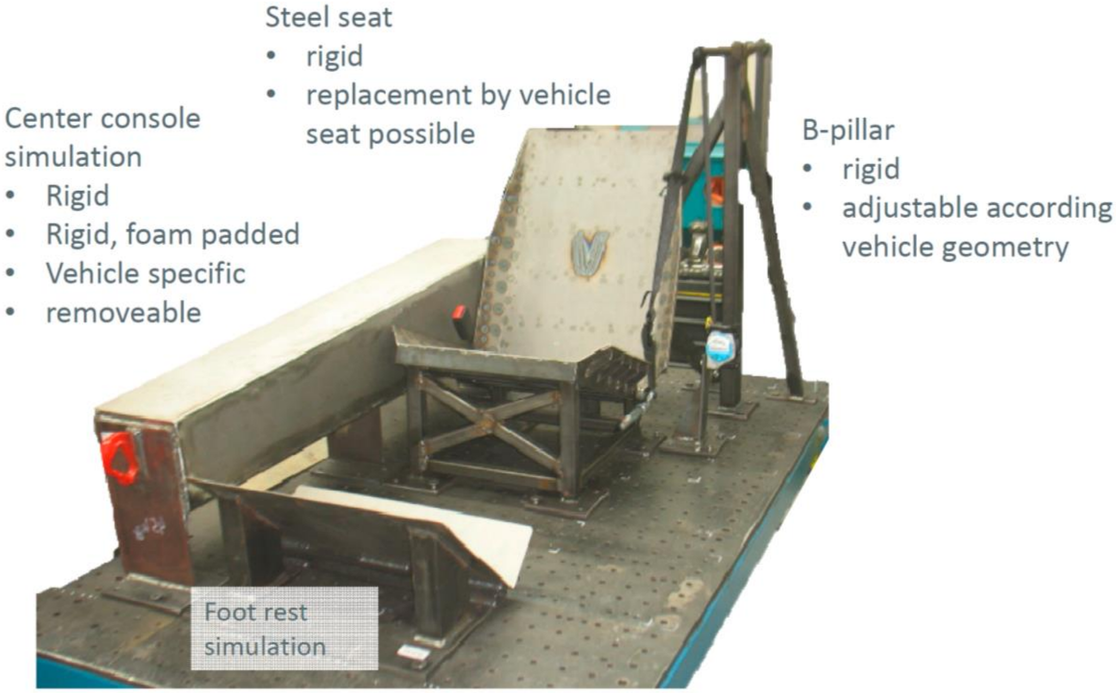
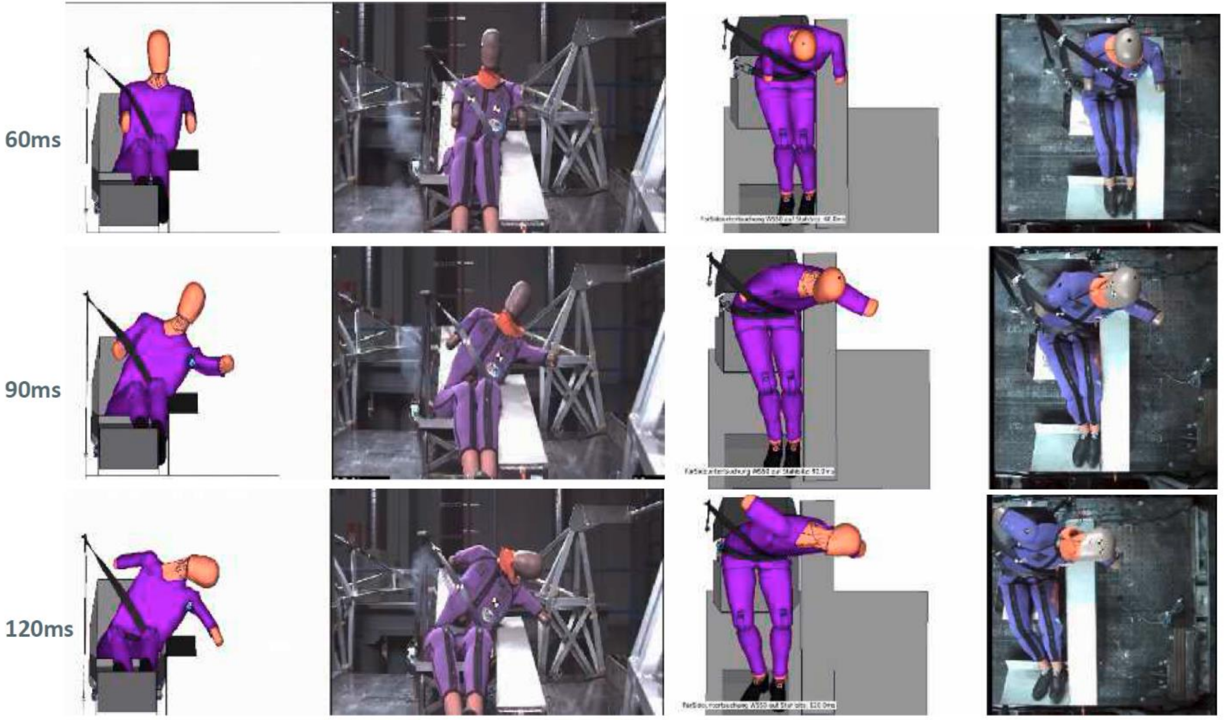
Appendix I
Accident data summary

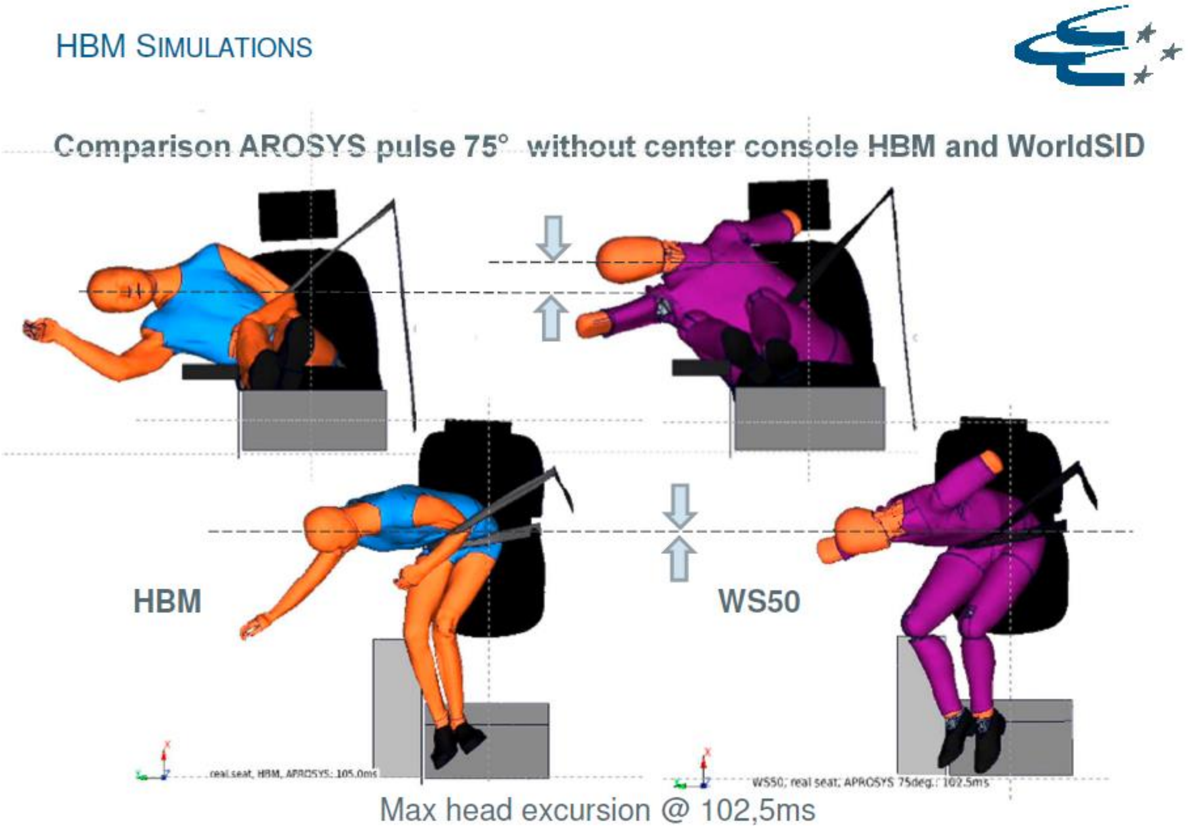
	GIDAS	**Volvo Cars Traffic Accident Database**	**BAAC French National Database**	**LAB (weighted data)**	**ADAC**	**RAIDS-CCIS**	**APROSYS**
Accidents	2005 – 2014 Germany Injured accidents No P or 2W	2002 – 2013 Sweden High repair costs	2010-2013 France Injured+ accidents (under reporting) No P or 2W	2005 – 2014 France Injured+ accidents No P or 2W	2005 – 2014 NO P OR 2W	1998 - 2010	ZEDATU CCIS PENDANT HIT GIDAS TNO DIANA BASC-CCIS
Impacts	Lateral						
Vehicles	Cars Reg. 2000+	Volvo cars MY 98+	Cars Reg. 2000+	Cars Reg. 2000+	Cars Reg. 2000+	1998-2010	1995+
Occupants	Belted drivers and front seat passengers						
Ages	10+	14+	10+	10+	10+	12+	
Sample	1,719 (804/915)	2,852 (1,295/1,557)	14,775 (6,801/7,974)	432 (199/233)	899 (374/525)	2108 (962/1146)	
MAIS 2+	99 (43/56)	41 (14/27)		172 (64/108)	538 (211/327)	585 (219/366)	
MAIS 3+	34 (9/27)	10 (1/9)		89 (34/55)	191 (74/117)	391 (141/250)	
Fatal & Seriously Injured			3,433 (1,391/2,042)				

Appendix II
Generic Sled setup



Sled and CAE comparison

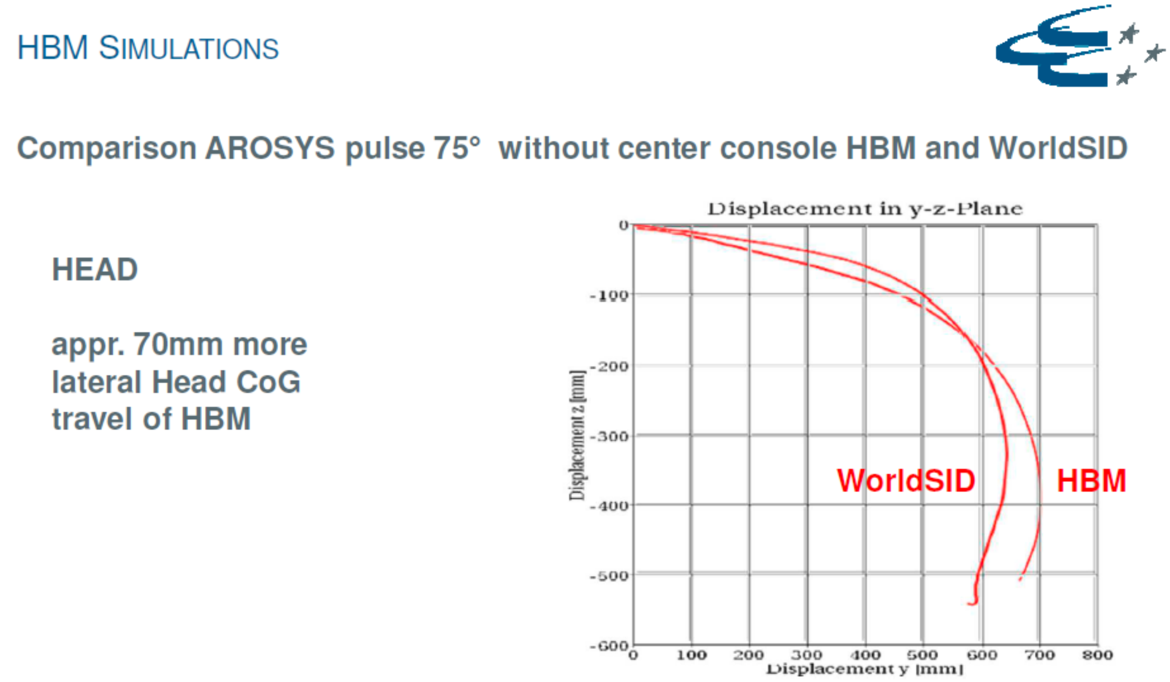




HBM SIMULATIONS

Comparison AROSYS pulse 75° without center console HBM and WorldSID

Max head excursion @ 102,5ms



HBM SIMULATIONS

Comparison AROSYS pulse 75° without center console HBM and WorldSID

HEAD

appr. 70mm more lateral Head CoG travel of HBM

Appendix IV
Sled test series 1

Test No.	1	2	3	4	5	6	7
Loadcase	AE-MDB					Pole	
Delta V	41km/h					42.4km/h	38.8km/h
Pulse	Generic modified Aprosys pulse					36 kph-75° Pole F164609	32 kph-75° Pole F164302
Angle of Impact				75°			
Occupant (Driver)	WorldSID half arm			WorldSID full arm	WorldSID half arm	WorldSID half arm	
Centre console present above H-point	Standard (119mm above H-point)				Large & strong foam block with 2mm tin layer (185mm above H-point)	Standard (119mm above H-point)	
Deploy struckside curtain airbag	yes (5,5ms) side glazing closed	No, if no head interaction in first test				No	
Deploy struckside airbag	yes (5,5ms)	No, if no arm/torso interaction in first test				No	
Deploy driver pretensioner				No			
Seat & dummy position				Euro NCAP			
Remark	Baseline	Repeatability		Full arm influence		Baseline	

Appendix V

Series 1 results summary table

Test-Nr.				1	2	3	4	5	6	7
Loadcase				AE-MDB					Pole	
Velocity (Km/hr) / Pulse				41 / Generic Modified Aprosys Pulse					36 / 75° Pole F164609	32 75° Pole F164302
Angle of Impact				75°	75°	75°	75°	75°	75°	75°
Occupant (Driver) WorldSID50				w/o Full Arm			With Full Arm	w/o Full Arm	w/o Full Arm	
Centre console (Xmm above H-point)				Standard (119)				"Big CC" (185)	Standard (119)	
Deploy of struckside SIAB & CAB (TTF, ms)				Yes (5,5)	No					
Deployment of Driver Retractor PT				No*						
Seat & Dummy Position				EuroNCAP						
Head	**HIC15**	**500**	**700**	310.29	227.62	187.92	344.33	501.70	114.51	84.67
	Accn. Res. (g)	**72**	**80**	58.20	50.30	46.45	59.61	74.01	37.03	33.40
Neck Forces - Max; Min	**Fx (kN)**			0.19; -0.24	0.31; -0.24	0.30; -0.21	0.23; -0.27	0.08; -0.36	0.15; -0.18	0.15; -0.19
	Fy (kN)			0.14; -0.50	0.16; -0.41	0.09; -0.38	0.10; -0.50	0.16; -0.68	0.10; -0.39	0.11; -0.39
	Fz (kN)		**3.74**	2.21	1.96	1.80	2.29	2.88	1.45	1.30
Neck Moments - Max; Min	**Mx (Nm)**		**-50**	-60.21	-51.80	-47.65	-57.07	-66.52	-33.84	-36.19
	My (Nm)		**-50**	-33.83	-38.79	-40.48	-38.57	-26.96	-33.93	-34.64
	Mz (Nm)			14.28; -16.75	15.43; -13.07	19.37; -16.18	13.94; -17.63	0.82; -11.82	13.84; -13.50	13.89; -13.77
Neck NIC	**Fx +; - (%)**			6.3; 7.8	14.1; 7.9	14.8; 8.8	7.4; 7.0	2.5; 12.7	6.6; 5.7	7.5; 6.1
	Fz +; - (%)			67.0; 0.1	62.5; 0.1	75.2; 0.1	87.5; 0.1	87.4; 0.1	51.4; 0.1	54.5; 0.1
Chest - Shoulder Force	**Res. Max (kN)**			1.38	1.69	1.55	1.45	1.84	1.44	1.11
	Fy Max (kN)			1.25	1.31	1.34	1.25	1.69	0.85	0.74
Thorax Rib Deflection (mm)	**1**	**-28**	**50**	-13.21	-7.83	-5.05	-4.37	-7.94	-1.06	-3.08
	2	**-28**	**50**	-14.21	-27.75	-6.89	-14.65	-10.74	-9.03	-23.06
	3	**-28**	**50**	-2.38	-13.90	-29.97	-6.09	-19.93	-35.75	-16.30
Abdomen Rib Deflection (mm)	**1**	**-47**	**65**	-1.76	-2.73	-8.86	-7.63	-45.65	-15.33	-1.97
	2	**-47**	**65**	-19.07	-21.29	-17.28	-25.07	-31.40	-2.48	-5.41
Pelvis	**Pubic ForceY (kN)**		**2.8**	-0.92	-0.90	-0.73	-0.68	-1.06	-0.70	-0.63
Lumbar	**Fy (kN)**		**2**							
Lumbar	**Fz (kN)**		**2.84**							
Lumbar	**Mx (Nm)**		**100**							
Remarks				with infl. Restraints shoulder belt trapped in sh joint (sh pad concern)	no top view camera in prel data no lower retractor fixation buckle opend	zipper opened by interaction suit w/ sh belt				

Appendix VI
Sled test series 2

Test No.	8	9	10	11	12	13	14
Loadcase	AE-MDB				Pole		
Main Evaluation Priority							
Delta V	41km/h				38.8km/h	38.8km/h	42.4km/h
Pulse	Generic modified Aprosys pulse				32 kph-75° Pole F164302	32 kph-75° Pole F164302	36 kph-75° Pole F164609
Angle of Impact				75°			
Occupant (Driver)	WorldSID half arm and sleeveless suit						
Centre console present above H-point	*Standard (119mm above H-point)*	*Standard (119mm above H-point)*	*Standard (119mm above H-point)*	*High console*	*Standard (119mm above H-point)*	*High console*	*Standard (119mm above H-point)*
Deploy of struckside curtain airbag	No	No	No	No	No	No	No
Deploy of struckside airbag	No	No	No, with spacer	No, with spacer	No, with spacer	No, with spacer	No, with spacer
Deploy driver pretensioner	No*	Yes;	Yes	Yes	Yes; 10ms	Yes; 10ms	Yes; 10ms
Seat & dummy position	Honda Jazz EuroNCAP	Honda Jazz EuroNCAP	Honda Jazz EuroNCAP	Honda Jazz EuroNCAP	Honda Jazz EuroNCAP	Honda Jazz EuroNCAP	Honda Jazz EuroNCAP
Remark	Record T1 and T4 acceleration Markers for	If pretensioning causes interaction with	Support B-pillar to PASSseat AND PASSseat to	Support B-pillar to PASSseat AND PASSseat to	Support B-pillar to PASSseat AND PASSseat to	Support B-pillar to PASSseat AND PASSseat to	Support B-pillar to PASSseat AND PASSseat to

Appendix VII

Series 2 results summary table

Far Side Occupant Protection - Sled Test Matrix											Crash	
Test No.				**S17120101**	**S17120102**	**S17120103**	**S17120104**	**S17120105**	**S17120106**	**S17120107**	**F164609**	**F164302**
Test No.				**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Pole**	
Loadcase				**AE-MDB**				**Pole**			**Pole**	
Velocity (Km/hr) / Pulse				**41 / Generic Modified Aprosys Pulse**				**32 75° Pole F164302**		**36 / 75° Pole F164609**	**36 / 75° Pole F164609**	**32 75° Pole F164302**
Angle of Impact				75°	75°	75°	75°	75°	75°	75°		
Occupant (Driver) WorldSID50				**WS50 w/o full arm - WITH sleeveless suit**							**w/o Full Arm - WITH sleeved suit**	
Centre console (Xmm above H-point)				**Standard (119)**			**"Big CC" (185)**	**Standard (119)**	**"Big CC" (185)**	**Standard (119)**	**Standard (119)**	
Deploy of struckside CAB - Yes / No (TTF, ms)				**No**							**Yes (5,5)**	
Deploy of struckside SIAB - Yes (TTF, ms)				**No**		**No - Support B-pillar to PASS seat AND PASS seat to centre console**						
Deployment of Driver Retractor PT				**No***	**Yes; 7ms**			**Yes; 10ms**			**No**	
Seat & Dummy Position				**EuroNCAP**							**EuroNCAP**	
Head	**HIC15**	**500**	**700**	**192.00**	**225.20**	**210.60**	**501.90**	**93.80**	**133.70**	**101.60**	**3305.41**	**253.77**
	Accn. Res. (g)	**72**	**80**	**47.00**	**51.60**	**51.00**	**70.50**	**36.00**	**39.20**	**39.10**	**370.98**	**72.84**
Neck Forces - Max; Min	**Fx (kN)**			**0.25 -0.27**	**0.37; -0.30**	**0.17; -0.24**	**0.07; -0.42**	**0.16; -0.18**	**0.05; -0.24**	**0.15; -0.25**	**0.05; -1.55**	**0.10; -0.24**
	Fy (kN)			**0.11; -0.47**	**0.15; -0.45**	**0.08; -0.51**	**0.15; -0.68**	**0.03; -0.48**	**0.09; -0.57**	**0.03; -0.40**	**0.31; -0.80**	**0.20; -0.60**
	Fz (kN)		**3.74**	**1.83**	**2.03**	**2.03**	**2.77**	**1.40**	**1.54**	**1.43**	**1.45**	**1.26**
Neck Moments - Max; Min	**Mx (Nm)**		**-50**	**-46.39**	**-44.64**	**-47.85**	**-56.59**	**-31.52**	**-44.52**	**-28.87**	**-16.31**	**-48.67**
	My (Nm)		**-50**	**-36.33**	**-48.19**	**-37.94**	**-23.41**	**-46.02**	**-32.70**	**-47.01**	**-60.28**	**-37.51**
	Mz (Nm)			**16.00; -17.83**	**19.79; -18.79**	**14.81; -15.84**	**3.34; -11.54**	**17.76; -19.22**	**4.63; -14.52**	**18.61; -19.41**	**4.67; -47.07**	**11.08; -23.93**
Neck NIC	**Fx +; - (%)**			**9.3; 8.6**	**14.4; 9.6**	**6.2; 7.9**	**5.8; 14.4**	**5.3; 10.0**	**1.8; 8.3**	**5.0; 14.0**	**1.5; 50.2**	**9.3; 7.8**
	Fz +; - (%)			**58.3; 0.1**	**61.6; 0.1**	**66.4; 0.1**	**84.0; 0.1**	**47.1; 0.1**	**46.6; 0.1**	**49.5; 0.1**	**44.1; 154.2**	**38.3; 66.5**
Chest - Shoulder Force	**Res. Max (kN)**			**1.68**	**1.55**	**1.58**	**1.78**	**0.97**	**1.19**	**0.95**	**1.35**	**0.92**
	Fy Max (kN)			**1.46**	**1.38**	**1.43**	**1.64**	**0.84**	**1.07**	**0.83**	**0.80**	**0.79**
Thorax Rib Deflection Max (mm)	**1**	**-28**	**50**	**-4.6**	**-7.1**	**-3.4**	**-6**	**-5.1**	**-4.1**	**-3.9**	**0**	**-0.04**
	2	**-28**	**50**	**-22.4**	**-26.1**	**-4.9**	**-9.5**	**-19.4**	**-6.9**	**-8**	**0**	**-0.17**
	3	**-28**	**50**	**-23.1**	**-10.2**	**-18.7**	**-21.6**	**-19.7**	**-21.3**	**-32.3**	**3.22**	**-1.59**
Abdomen Rib Deflection Max (mm)	**1**	**-47**	**65**	**-7.9**	**-3.1**	**-11.2**	**-40.7**	**-7**	**-26.1**	**-14.2**	**-2.66**	**-4.26**
	2	**-47**	**65**	**-24.8**	**-1.9**	**14.4**	**-30.5**	**-5.6**	**-16.2**	**-2.6**	**-5.57**	**-6.93**
Pelvis	**Pubic ForceY (kN)**		**2.8**	**-0.78**	**-0.82**	**-0.77**	**-1.01**	**-0.77**	**-0.7**	**-0.75**	**-0.66**	**-0.69**
			2									
			2.84									
			100									
Remark				Cut in new sleveless suit; no belt interaction with dummy shoulder / jacket	Belt height adjuster in lowest posn. +1 notch instead of up; no belt interaction with dummy shoulder / jacket							

Euro NCAP - New Frontal Impact Test with Mobile Progressive Deformable Barrier (MPDB)

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ABSTRACT

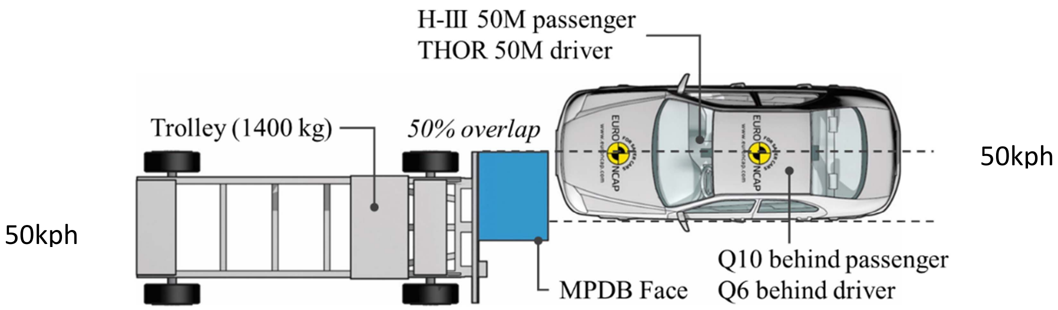
In 2015 Euro NCAP announced that the current offset deformable barrier frontal impact test procedure would be revised and a frontal impact working group was set-up to develop the new procedure. The aim was to bring together individual research efforts by FIMCAR [1], ADAC and other organisations [2,3] on the development of a 'moving barrier to vehicle' frontal impact test and derive common specifications for the new Euro NCAP test and assessment procedure from this. In partnership with the European Enhanced Vehicle safety Committee (EEVC), Euro NCAP examined the extent to which the advanced frontal THOR-M ATD is ready and suitable for use in this new test procedure. The overall results of the accident analyses, the specification of the test setup and the definition of the barrier were reported at the ESV 2017 in Detroit [4]. In the subsequent stage, the group focussed on the assessment criteria for the THOR dummy, the compatibility assessment and the full-scale evaluation of the procedure. Several round robin tests were organised to check the feasibility and repeatability of the method, in particular with regards to the THOR dummy and the barrier scanning. The group has released the final test and assessment protocols in 2018 for adoption in 2020, but will continue to monitor relevant developments, in particular related to dummy hardware and certification updates.

BACKGROUND

In the first phase of work of the group, the basic foundations for the definition of the new frontal mobile barrier test were laid, especially test parameters like impact speed overlap, mass of the barrier, the definition of the mobile barrier face and the dummy positioning in the test vehicle. The new test is aiming at improving the biomechanical assessment of critical body region risk at injury and at assessing, for the first time, vehicle compatibility. As NHTSA has postponed the introduction of the new US NCAP that was announced in 2016, Euro NCAP will most likely be among the first world-wide to use the advanced THOR-M dummy as part of their assessment of vehicle's crashworthiness. Several relevant documents pertaining the specification and certification of the latest dummy hardware remain unreleased by NHTSA until this date, which meant that the working group had to verify the latest built-level dummy's repeatability and reproducibility and make some practical decisions regarding certification. Beside the dummy specification, injury criteria and the upper and lower reference values (limits) for the rating needed to be set. The biggest challenge, however, was to agree on the method by which vehicle compatibility could be assessed and included in the safety rating. Finally, the complete test procedure by R&R testing needed to be validated, so several test series were carried out in the Euro NCAP accredited laboratories to verify the test setup and assessment and to proof the test's reproducibility in different labs with the same result.

TEST SPECIFICATION

The actual car-to-barrier test specification was agreed in 2016 with both the vehicle and the barrier approaching at 50kph (MPDB). The test vehicle is equipped with a THOR 50th percentile male dummy (THOR 50M) on the driver seat and a Hybrid III 50th percentile male dummy (H-III 50M) on the front passenger seat. In the second row, a Q10 dummy is placed on the struck side while the Q6 dummy is seated on the non-struck side, the results of which are used for the Child Occupant Protection assessment in Euro NCAP. The overlap is moderate at 50 percent of the total vehicle width. The moving trolley carries a progressive deformable barrier [5,6] on the front outboard side and has a mass of 1400kg (Figure 1).



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igure 1: Impact condition of the MPDB test

ASSESSMENT CRITERIA

Euro NCAP has carried out the frontal offset deformable barrier (ODB) testing for more than 20 years. During this time, there have only been minor changes to the assessment of the vehicle performance. From the beginning, the test score was based on actual dummy scores (based on injury limits) and so-called modifiers, which can reduce the number of scored points from the dummy values, due to observations made in the high-speed films, dummy traces or based on structural problems in the vehicle such as deformation or potential risks for the passengers. This kind of assessment, which is also used in other full-scale tests, was also followed for the new MPDB test. With the assessment of the barrier/trolley performance for compatibility, a new modifier was introduced for the overall frontal performance of the tested vehicle.

Approach

Euro NCAP's assessment of driver and passenger occupant protection will be based on dummy values, derived from lower and higher performance limits against a set of dummy criteria, and restraint and structural modifiers, such as airbag failure, pedal intrusion etc. Contrary to Hybrid-III, there are few industry accepted injury limits for THOR available and there is still a lack of information of injury risk curves or dummy limits published in the scientific community. The group analysed data from the round robin tests, ongoing research, publications and studied comparable tests between the Hybrid-III 50M and the THOR 50M to find correlations and set the first criteria and limits for the THOR 50M dummy.

THOR Assessment Criteria

The initial list of criteria included more or less all parameters which have been considered by NHTSA, with the exception of those related to the THOR-LX as Euro NCAP has decided to use the Hybrid III 50% lower legs in the first step. These criteria are:

- HIC15
- BrIC/SUFHEM (monitoring)
- Neck forces and torque
- Chest displacement / Rmax
- Abd compression
- Left acetabulum load
- Right acetabulum load
- Left femur force
- Right femur force
- Left knee shear displacement
- Right knee shear displacement
- Left tibia index
- Right tibia index
- Left tibia compression
- Right tibia compression
- Pedal rearwards displacement

Lower Leg, Knee and Femur At the time that the group defined the THOR 50M specification in 2016, the decision was taken not to adopt the LX-legs, due to the status of the development of the legs, the high costs of obtaining and certification of the legs, and the relative low priority of lower leg injuries in the field. So, the Hybrid-III 50M lower legs were applied to the THOR femurs, including the knee slider of the Hybrid dummy. With the use of the Hybrid III parts, also the current Hybrid III 50M dummy criteria and upper and lower performance limits could be used for assessment. This includes the Tibia Index, the Tibia Force F_z and the knee slider performance. Euro NCAP also continues to monitor pedal rearward displacement and foot well behaviour as part of the modifier assessment, a practical measure that has been an effective way to minimise the risk at foot and lower leg injuries in practice.

The other parts of the THOR assessment in the lower extremity area are the femur and the acetabulum. The Femur load is also based also on the Hybrid III 50M value and is evaluated in used in the compression phase. A preliminary NHTSA publication showed comparable values for H-III and THOR so the higher performance limit was set to 3,8kN and the lower performance limit to 9,07kN. The acetabulum calculation takes the resultant force of F_x, F_y and F_z into account. Often the tension force F_x produces higher values than the compression force, but tests have shown that the compression force is the driving factor of injuries in the acetabulum region. Due to this fact, high resultant values of the acetabulum might not be problematic for the passenger as this will be result of the tension force primarily. To solve this issue, the Euro NCAP acetabulum calculation foresees that the resultant force is only calculated in the phase when F_x shows compression. The proposed limits were set to 3.28 as lower performance and 4.1 as higher performance limit.

Chest and Abdomen Actual crashes analysed by the group showed that chest and abdominal injuries are still the most common injuries in frontal impacts on European roads. This was the main motive to introduce THOR in the new frontal test. This dummy was designed to be more biofidelic in the chest and abdomen area than the Hybrid III dummy. The interaction with the restraint systems is expected to be more humanlike, due to its higher spine flexibility and improved anthropometry. Despite these advantages, however, the idea of using an advanced chest injury risk criterion of based on a combination of chest compression and geometric deformation, such as the PCA-score, turned out to be premature, as there is still work ongoing and only limited data are available to support biomechanical limits. In the introduction phase, the maximum deflection R_{max} will be the assessed criterion in the chest region. All ribs will be evaluated, while the rib with the highest compression is driving the assessment. The results of the SENIORS project [7] and the internal test runs of MPDB test from Euro NCAP were used to set acceptable upper and lower performance limits. It was also understood that the current vehicles tested were not optimized for the new dummy and future performance in cars will likely show better results. Based on these studies, the lower performance limit was set to 35mm, while the higher performance limit of 60mm is used.

Unfortunately, even less information is currently available regarding abdominal injury risk. Due to this fact, and primarily based on the experience in the full-size crashes, only the upper performance limit was defined, which will allow to Euro NCAP to identify vehicles showing elevated submarining risk. In addition, ASIS load cells will help to detect issues in performance of the lap belt section.

Head and Neck The current Euro NCAP assessment of the head includes the HIC_{15} and the 3ms resultant acceleration, taken from the dummy measurement. Both criteria will be also used with the THOR dummy as there is no influence of the dummy construction which might influence these criteria. These criteria however are not adequate to accurately assess brain injury risk and therefore additional criteria are under discussion for AIS 2+ injuries in front impact crashes. As further research is needed on this topic, Euro NCAP delayed the introduction of a brain injury risk criterion to 2022. In the meanwhile, it will monitor several possible criteria such as BrIC, UBrIC and criteria which include simulation models i.e. SUFHEM. HIC_{15} lower (500) and upper (700) values will be applied as well as the resultant acceleration 3ms limits of 72g for the lower performance limit and 80g for the upper performance limit.

For the neck, Nij was not adopted. Instead, neck forces and bending moments are used for assessment, as is the case for the Hybrid HIII 5F and 50M. Comparing MPDB tests with the THOR and Hybrid III dummies, it was found that the neck tension force F_z correlates well between these two dummies and could be transferred to the THOR assessment, with a lower performance limit of 2.7kN and an upper performance limit of 3.3kN. This correlation could also be seen in certification tests, while shear force F_x and extension moment M_y did not show such correlation whether in certification or in vehicle crash tests. Euro NCAP continues to study the neck injury criteria and currently proposed limits remain to be confirmed at time of submitting this paper.

The situation with neck injury assessment is exacerbated by continuing neck certification issues as several production level THOR necks have not been passing the certification corridor that was previously agreed with the dummy manufacturer. This issue needs to be solved first, before final values for upper and lower performance of neck criteria can be defined.

In Table 1 all relevant criterion, with upper and lower limits are shown, as well as the point’s calculation. The assessment is based on the worse scoring parameter of each individual body region and the overall score on the worst scoring body region of the driver and the passenger. The passenger scoring remains unchanged from the ODB assessment in 2019.

Table 1
Injury criteria for THOR 50M ATD

Body Region	Criterion	Unit	Upper	Lower	Scoring*
Head	HIC15		700	500	4 points
	SUFEHM				
	BrIC				
	A Resultant 3ms	g	80	72	
Neck	Fx	kN	3.1	1.9	
	Fz	kN	3.3	2.7	
	My	Nm	57	42	
Chest & Abdomen	Chest compression / Rmax	mm	60	35	4 points
	Abdominal Compression	mm	88		
Knee, femur, pelvis	L/R Acetabulum	kN	4.1	3.28	4 points
	L/R Femur compression	kN	9.07	3.8	
	L/R Knee shear displacement	mm	15	6	
Lower leg	L/R Tibia index		1.4	0.4	4 points
	L/R Tibia Compression	kN	8	2	

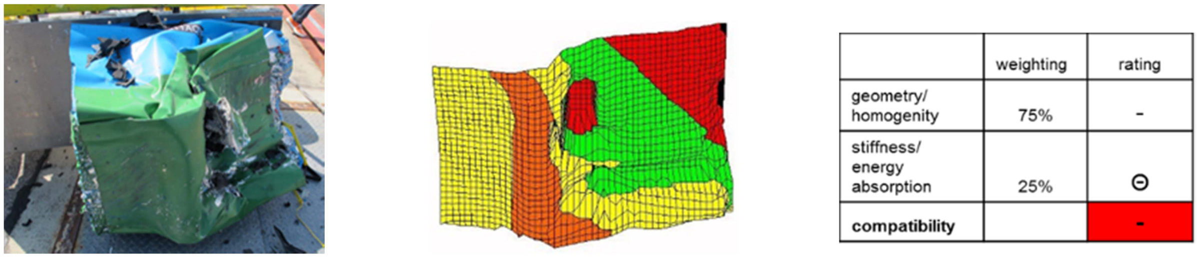
**Based on worst-case parameter*

Dummy Certification
With the introduction of the Service Built Level (SBL) B of the THOR 50M, also a certification procedure needed to be established. The lower leg and knee certification is based on the Hybrid III certification but from the femur to the head, a new set of certification procedures and limits were proposed, based on the THOR 50M, Qualification Procedure Manual 2016. This procedure is defined in the TB26 [8] of Euro NCAP.

COMPATIBILITY ASSESSMENT

Rationale

Former research on compatibility has identified mass differential, stiffness of front structures and geometric alignment as the parameters most influencing vehicle incompatibility. The impact scenario of the proposed MPDB with 180° impact angle, will lead to a nearly vertical loading of the barrier, which enables a good calculation of the energy transfer into the barrier and measurement of the footprint in the barrier. ADAC previously used this scan in their assessment to rate the geometry and the stiffness of the tested vehicle [9], see Figure 2. The idea behind this assessment is to rate the homogeneity of the front structure. The flatter the surface, the better the load spread.



	weighting	rating
geometry/ homogenity	75%	-
stiffness/ energy absorption	25%	⊝
compatibility		🟥 -

Figure 2. PDB barrier scan and compatibility assessment by ADAC

To investigate both the longitudinal and the area outside of the longitudinal, an assessment area is defined on the barrier front which depends on the vehicle width. The standard deviation of the intrusion in this assessment area is calculated, see Figure 3. The intrusion measurement is done by scanning the barrier footprint after the test. This is the first part of the assessment, reflecting geometry/ homogeneity.

The second part of the assessment is the deceleration of the mobile barrier and the energy absorption of the deformable element in the assessment area. The idea behind is to decelerate the trolley as slowly as possible, to avoid unnecessary loading of the partner car. Also, the less energy the test vehicle puts in the barrier the less energy the partner car needs to absorb. If stiff front-end vehicle parts bottom out the barrier, there will be an additional downgrading modification of the assessment. For this, a maximum intrusion of 633mm is proposed. The penetration of 633mm results in the maximum deformation of the first and the second honeycomb element and the block length of the honeycomb material and no deformation of the last element.

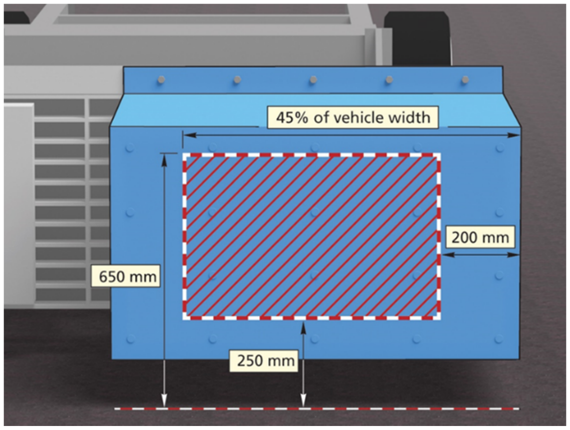


Figure 3. Compatibility assessment zone

The points distribution and the potential impact of the compatibility modifier on the rating was chosen to maximise the incentive for vehicle manufacturers to improve their structures, given what is feasible in a relatively short period. A good interaction between the different front structures is essential to activate the crash zones and to reduce the impact energy. Examples of a good geometric design, which helps to distribute the loads in several levels and also outside the longitudinal, are already available on the market and are easier to adopt than totally new crash energy management systems, which will take longer to implement and must be designed early in the construction process. Hence a weighting of the various rating elements was chosen that would incentive compatibility improvements in the fleet in a faster way.

The main elements used in the assessment were barrier scanning and calculation of the footprint and standard deviation, and the energy management of the barrier and trolley deceleration. As there was no clear proof from the accident data which of these two criteria should be prioritised, both are rated equally. Some of the vehicles tested, however, had very stiff longitudinal frames, which was seen to be critical in car to car impacts. Their localised “punch” effect could be reproduced in the MPDB test, however as this results in a relatively small area of penetration, this issue is not necessarily adequately reflected by the standard deviation. Therefore, it was decided to have this separately assessed and penalised in the score. Finally, the Occupant Load Criterion [10] was considered as the best way to evaluate energy management by assessing the vehicle stiffness indirectly with the barrier deceleration pulse.

In summary, the three agreed parameters for assessing the compatibility were:

- Standard deviation (SD) of the post-test barrier measurement,
- Occupant load criterion (OLC), according the deceleration pulse of the barrier,
- Bottoming out, measured by intrusion depth of the honeycomb.

Standard Deviation (SD)

The homogeneity measurement is based on standard deviation (SD) of the measurement of the intrusion depth in the assessment zone (Figure 4). The assessment zone was taken over from the original ADAC rating as there was a lot of experience of testing vehicles against progressive deformable barriers faces. Due to the movement of the vehicle after the impact, the outboard side of the barrier will be loaded sideways, and the honeycomb faces are bent instead of compressed. This will result in a different deformation, so a distance of 200mm is excluded from the outboard side to the assessment zone. Due to issues in the upper and lower area, resulting from behaviour of the cladding sheet, the lower rating area was set to 250mm from ground, while the upper area was set to 650mm from the ground. The width is based on 45% of the vehicle width.

The standard deviation is defined as the spread around the mean intrusion that covers 68.2% of all measured intrusion points. The bigger the standard deviation the bigger the spread of the intrusion points and the less the homogeneity of the structure. Steps in the deformation zone, such as single cross members, no structure in front of the road wheel etc. could be detected. The assessment of the SD is based on a linear scale from 50mm, higher performance limit, to 150mm, which is the lower performance limit.

Reproducibility of the scanning method to ensure that the scanning process and the used tools produced repeatable and reproducible SD results, the labs were trained how to deal with different deformed elements, ruptured barrier etc. Solutions were worked out to treat problems during scanning such as reflexions, open hexagons, etc. After that, one barrier was sent out to 5 different Euro NCAP accredited laboratories to perform a scan round-robin test. The barrier of the round robin was scanned in the individual labs, with different equipment and test crew. The results are shown in Table 2 as well as the different scans in Figure 4.

Table 2

SD of barrier scans measured at different labs

Laboratory	Standard Deviation Measured (mm)
Lab1	42
Lab 2	42
Lab 3	41
Lab 4	42
Lab 5	41

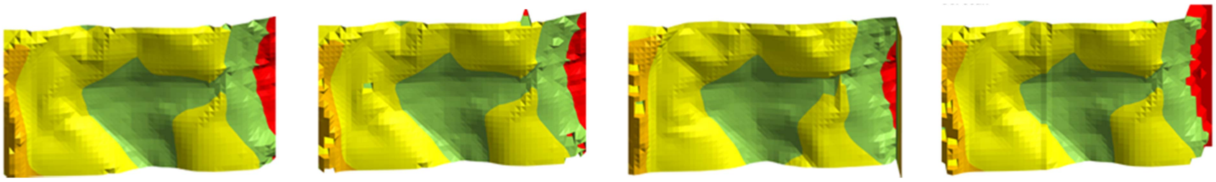


Figure 4: Barrier scans round robin results for 4 out of 5 laboratories

Occupant Load Criterion (OLC)

The occupant load criterium is based on the measured deceleration in the CoG of the trolley during the impact. After filtering the deceleration signal with CFC 180, the pulse should be integrated with the following equation to derive the velocity course of the barrier.

$$V_t = \int A_X(t)\, dt + V_0$$

Where V_0 is the initial velocity of the barrier at t = 0s. $OLC_{SI\text{-unit}}$, t_1 and t_2 can by calculated by the following equation system:

$$\begin{cases} \int_{t=0}^{t=t_1} V_0\, dt - \int_{t=0}^{t=t_1} V(t)\, dt = 0.065 \\ \int_{t=t_1}^{t=t_2} \left(V_0 - OLC_{SI-unit} \times (t - t_1)\right) dt - \int_{t=t_1}^{t=t_2} V(t)\, dt = 0.235 \\ V_0 - OLC_{SI-unit} \times (t_2 - t_1) = V(t_2) \end{cases}$$

Where t_1 is the end of the free flight phase of a virtual dummy on the trolley along a displacement of 0.065m and t_2 is the end of the restraining phase of a “virtual occupant” on the trolley along a displacement of 0.235m after the free flight phase, resulting in a total displacement of 0.300m for the virtual occupant (Figure 5). For the compatibility assessment the OLC is converted into SI units (1g= 9,81m/s2). The OLC is evaluated using a sliding scale from 25g higher performance limit to 40g lower performance limit.

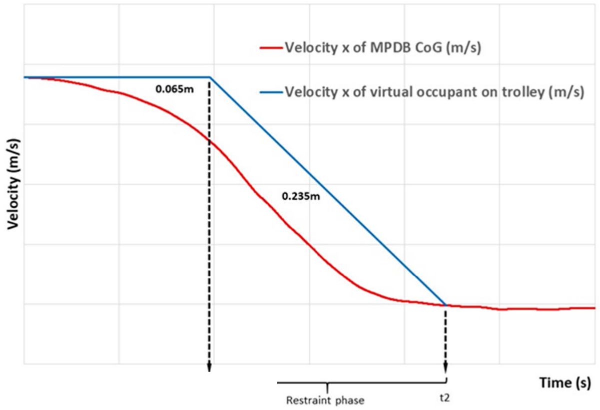


Figure 5. OLC and trolley velocity

Bottoming Out

Bottoming out defines an area where a structure of the vehicle penetrated the barrier more than 630mm in depth and a width of more than 40mmx40mm.

Compatibility Modifier

In the Euro NCAP rating scheme, maximum 16 points can be gained in the MPDB test, if all dummy criteria stay below the higher performance limits and no modifiers are applied. The contribution to the Adult Occupant Protection is half of that score, so a maximum 8 points, similar to the 8 points contribution of the Full-width frontal test.

The result of the compatibility assessment will be applied as a modifier to the total score of the MPDB test. The maximum modifier will be 8 points and will reduce the number of scored points of the occupant rating. In the first phase from 2020 to 2022, the result of the modifier will be limited to maximum of 4 points however to allow industry to adjust their vehicles step-wise. Both, the standard deviation (SD) and the OLC are assessed with a sliding scale with the upper and lower limits mentioned above. The bottoming out modifier is then added to the result. The general scoring rational is shown in Figure 6.

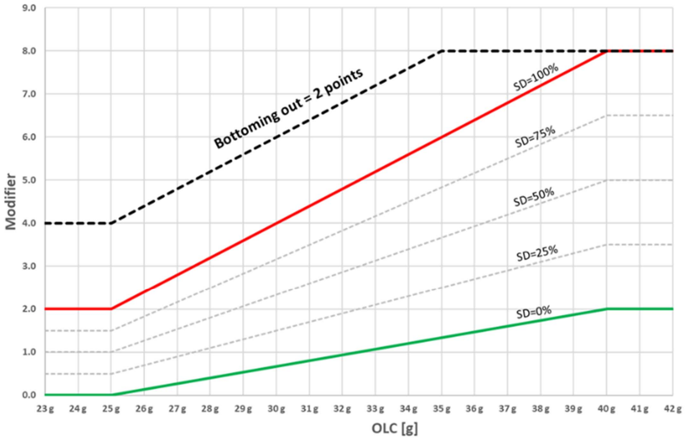


Figure 6. General scoring rational [8]

VERIFICATION TESTS

A final check of the assessment procedure was carried during a final round robin full-scale test series. As part of this series, two pairs of vehicles were tested in different labs to check the test variation in setup, dummy results and compatibility assessment. The vehicles tested twice were the 2017 5-stars rated Honda Civic and the 2017 5-stars rated Ford Fiesta. Other vehicles were chosen to represent, different types of vehicles. Large SUV, smaller SUV, Supermini´s as compact class cars were included. All cars were tested to assess the dummy values and the compatibility modifier. The following table is showing all tested vehicles during the 2nd round robin tests carried out in 2018.

Table 3

Full-scale validation MPDB test series: cars models, labs and barrier suppliers

Model	Description	Lab	Barrier face
Honda Civic	5-star compact class (expected to show good compatibility assessment)	ADAC	Cellbond
		IDIADA	Cellbond
Ford Fiesta	5-star car used for validation tests (expected to show moderate compatibility)	BASt	AFL
		TASS	AFL
Jeep Renegade	Compact 5-star SUV	CSI	Cellbond
Jag E-Pace	Compact 5-star SUV vehicle (expected moderate compatible structure)	TASS (Thatcham)	AFL
Renault Clio	Supermini 5-star (expected to show good compatibility)	UTAC	AFL
Audi Q5	Large 5-star off-road vehicle, representing SUVs (expected not to have a compatible structure)	ACTS/CLEPA	Cellbond

Dummy Results

In the initial phase of the working group's research, several R&R tests were carried out including sled tests, vehicle tests and certification tests to verify the reproducibility and durability of the latest THOR 50M and to identify what updates to the dummy would still be needed. Since then, several improvements were adopted, related to the dummy hardware, handling and certification. The largest step forward was the definition of a Service Built Level of the dummy, because up until that time many of the THOR dummies in the field were of a different built status, causing much confusion and frustration amongst the user community. During the round robin validation tests, all THOR 50M dummies were brought up to SBL-A (later followed by B) to avoid unnecessary discussions and wasting valuable resources.

In the first set of cars, two 2017 Honda Civic were used, a five-star Euro NCAP car with an ODB assessment score of 7.1 pts. This car was tested in 2 different labs, with 2 different THOR dummies on the driver seat. The overall results showed that there was no significant change in performance in the head/neck and knee/femur/pelvis area between the two lab results. The lower legs, which showed in the ODB test good results scored 0, respectively 0,09 points, in the MPDB tests, due to the values of the lower Tibia Index, which was unexpected. On the other hand, the chest deflection, Rmax showed a chest injury risk that was significantly higher than in the original ODB with the Hybrid III, as anticipated. The deflection values between the two MPDB tests were significant different owing to different belt behaviour as could be observed in high speed video. All other values showed equivalent results, as shown in Table 4.

Table 4

Full-scale validation MPDB test results: Paired comparisons

	Honda Civic (2017)		Ford Fiesta (2017)	
	IDIADA	ADAC	BAST	TASS
Head & Neck	4.00	4.00	4.00	4.00
Chest & Abdomen	0.80	2.02	0.26	0.11
Knee, femur, pelvis	4.00	4.00	4.00	4.00
Lower Leg	0.00	0.09	2.67	2.15
Total	8.80	10.11	10.93	10.27

The second set of cars that were tested under the same condition but in different labs, was the 2017 Ford Fiesta.
In the 64kph ODB test with the Hybrid III dummy on the driver seat, the overall performance was excellent, scoring 7.7 points out of 8 points. In the MPDB test, the Ford Fiesta scored less points in the chest and the lower leg area. The results of both test labs matched quite well.

A similar conclusion could be drawn from the remaining vehicles tested in this series. As expected from the THOR 50M the chest area is the predominant cause for points reduction, followed by the lower leg area. Even the larger cars such as the Jaguar E-pace and the Audi Q5 demonstrated weaker performance in the chest area, sometimes exceeding the lower performance limit significantly. Higher Tibia Index values were the main cause for lower scores in the lower legs. All results of the round robin 2 could be seen in Table 5.

Table 5

Full-scale validation MPDB test results: All cars

	Honda Civic	**Honda Civic**	**Ford Fiesta**	**Ford Fiesta**	**Jeep Renegade**	**Renault Clio**	**Jaguar E-Pace**	**Audi Q5**
	IDIADA	ADAC	BASt	TASS	CSI	UTAC	TASS	ACTS
Head & Neck	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Chest & Abdomen	0.80	2.02	0.26	0.11	2.58	0.00	2.71	0.00
Knee, femur, pelvis	4.00	4.00	4.00	4.00	4.00	2.01	4.00	4.00
Lower Leg	0.00	0.09	2.67	2.15	3.64	0.93	3.49	2.67
Total	8.80	10.11	10.93	10.27	14.23	6.94	14.20	10.67

Compatibility Assessment
All vehicles in the previous and final validation test series were rated according the agreed version of the compatibility assessment. Figure 7 shows the modifier on the LHS according the OLC on the x-axis. The red line shows the SD of 100% and the green line at 0%. The overall results show a wide spread of results, but also the differences between vehicle classes.

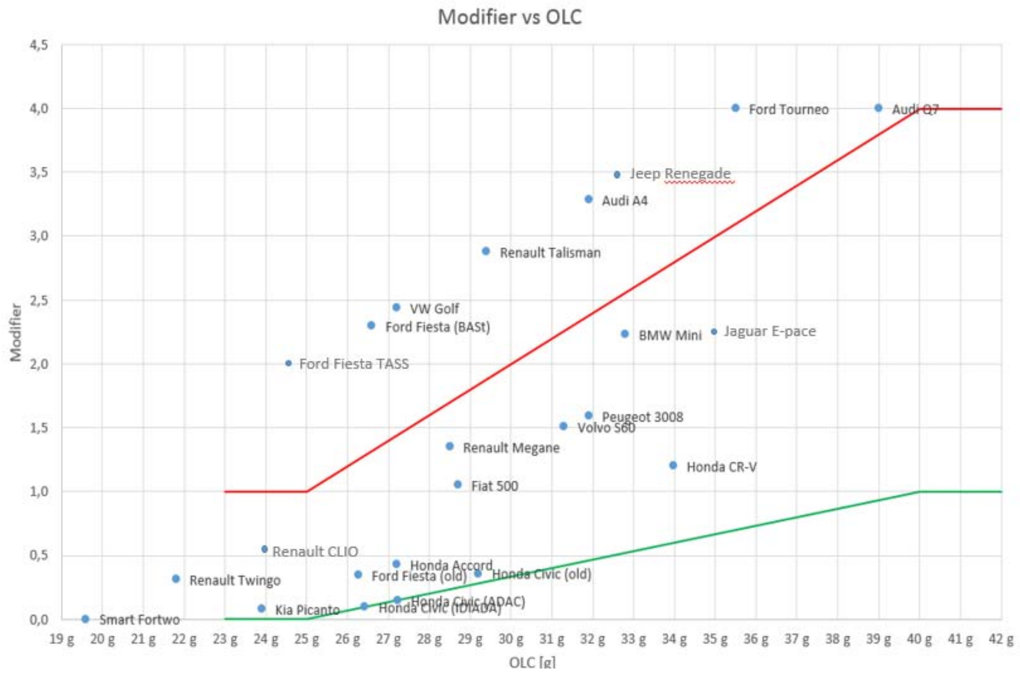


Figure 7. Compatibility Rating for cars tested in first and second validation test series

Small SUV`s such as the Jeep Renegade, the Jaguar I-Pace and the Honda CR-V, show a significantly drop in modifier scoring, even their OLC is more or less the same. On the other hand, vehicles of the same mass show a reduction in OLC, which means with a different front structure the accident partner could be loaded less. Examples are the Audi A4, the Renault Megane and the Honda Accord, while the Audi showed the highest OLC.

Both test pairs of Fiesta and Civic show a good reproducibility of the compatibility assessment. In different test labs, and with cars not being designed for this load case, the overall compatibility result shows only minor differences. In the case of the Fiesta it is 0.1 points difference, while in the Civic test it is only 0.05 points difference. Even as the footprints in the Ford Fiesta test were not exactly identical, due to a slightly different behaviour of the front cross member, the overall compatibility assessment itself is not really affected, which demonstrates that the method of the assessment itself is robust. In case of the Honda Civic, both footprints also showed nearly identical measures (Figure 8). Bearing in mind the small variations that can occur in the scanning process, the overall compatibility assessment shows to be repeatable and robust.

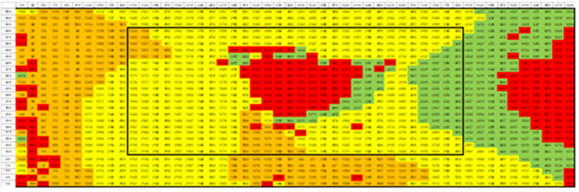
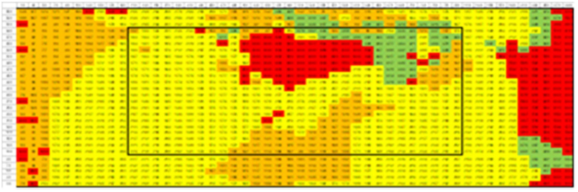
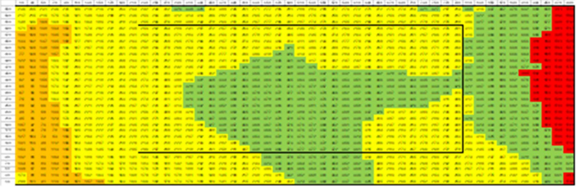
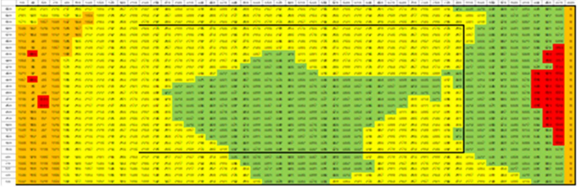
<table>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>2017 Ford Fiesta
(BASt)</td><td>SD: 148
OLC: 26.6
Bottoming out: -2
Overall: -2.1</td><td>2017 Ford Fiesta
(TASS)</td><td>SD: 158
OLC: 24.5
Bottoming out: -2
Overall: -2.0</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>2017 Honda Civic
Fiesta
(IDIADA)</td><td>SD: 42
OLC: 27.2
Bottoming out: 0
Overall: -0.15</td><td>2017 Honda Civic
Fiesta
(ADAC)</td><td>SD: 45
OLC: 26.4
Bottoming out: 0
Overall: -0.1</td></tr>
</table>

Figure 8. Comparison of barrier scans from full-scale tests

CONCLUSIONS

In the second and final phase of the development of a new frontal impact test with a mobile barrier, the work has focussed on dummy criteria, dummy certification and the new compatibility assessment. As there was only limited information available on the THOR-dummy injury risk curves, sled and full-scale crashes were carried out to find appropriate upper and lower limits of the different body regions that could be applied from 2020 onwards. Some practical considerations were used to decide on the limits. The repeatability and reproducibility of the dummy in certification tests was also studied and certification corridors for THOR 50M use for Euro NCAP testing were agreed.

The definition of a built level allowed the group to carry out round robin tests to validate the procedure, criteria and also to confirm the reproducibility of the test. The results showed that under the new configuration of this frontal test, the THOR was usable and durable. The chest and lower leg will be the more demanding body regions for the future assessment, as nearly all the cars showed lesser performance in this area compared to the ODB results. It appears that the chest result was influenced by the THOR chest behaviour, the restraint systems not being developed to accommodate for the more flexible rib cage. The lower leg result seems to be caused by the new test condition, as there was no change in the legs themselves (i.e. Hybrid III legs).

After decades of discussions on compatibility and possible ways to assessment it, a way was agreed in the Euro NCAP frontal impact group to rate the compatibility of test vehicles. Internal test series have shown that the barrier and deceleration assessments correlate with car to car crashes. R&R work in the group, carried out together with suppliers and vehicle manufactures, show a stable test procedure with repeatable and reproducible results. Even the assessment criteria may need further consideration in future, the first step was undertaken to use this test device in a consumer test program.

More work will be undertaken by Euro NCAP in the way to assess brain injuries and improve chest assessment taking the whole chest loading into account. Even without these advanced criteria, however, it is expected that the introduction of the new test will still promote the development of better restraint systems.

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GUIDELINE FOR A VEHICLE PURCHASE POLICY AIMING AT A SAFE AND SUSTAINABLE VEHICLE FLEET

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ABSTRACT

Vehicle safety and emissions are addressed in the UN Sustainable development goals 3.6, road traffic safety, and 13, reduced climate impact. In Sweden, a large proportion of new passenger vehicles (62%, 236 546 vehicles) were purchased by legal entities in 2017. Those vehicles are driven for 18 years in average. Therefore, well-reasoned company car policies in terms of safety and emissions are imperative to meet the global goals.

The objective was to show how a company car policy that includes requirements regarding safety and CO_2 emissions can be a tool to reach global safety and environmental goals. The paper describes the development of a vehicle purchase policy that was introduced by Folksam Insurance Group in 1998. The criteria of the policy have been revised on a yearly basis to meet developments of vehicle safety and environmental technology, as well as environmental goals.

The vehicle data consists of new passenger vehicles available on the Swedish market. Data regarding crash tests, safety equipment and CO_2 emissions are listed for every vehicle model and version. The safety requirements cover crashworthiness, performance in whiplash tests, and availability of selected safety systems. The environmental criteria are adapted to meet global goals regarding CO_2 emissions. The goal is zero carbon emissions from new vehicles in 2030. A general goal is that approximately 15 % of the new vehicles on the Swedish market should fulfill the requirements in the policy.

It is shown in this study that safety and environmental criteria have changed rapidly during the last two decades. Furthermore, it is shown that safety and emission policies are important tools to guide fleet procurement managers as well as private consumers. A comparison of vehicles for sale and with those that are actually sold shows a higher rate of safety assist system in sold models compared to models for sale. The CO_2 emission requirement has been halved during the two decades the policy has been active, indicating that the vehicle fleet has made large progress in reducing their CO_2 emissions as the proportion of vehicles fulfilling the requirements has been approximately 15% during the two decades.

It is important to guide vehicle fleet buyers of vehicles for private use to choose the safest and most environmentally friendly vehicles since those vehicles will be used for many years. Company car policies are important tools in this process. A vehicle purchase policy will indirectly influence car manufactures to offer vehicles that fulfil the requirements in the policy.

An important recommendation is that a vehicle purchase policy should be revised annually to follow rapid changes in available safety technology and emission standards in order to substantially influence the vehicle fleet. A vehicle purchase policy is an important tool to guide vehicle consumers towards the safest and most sustainable vehicles. It is recommended that a vehicle purchase policy should consist of requirements regarding crashworthiness, fitment of important safety systems, CO_2 emissions. Preferably, it should be complemented with a vehicle list for tangible and feasible advice to consumers.

BACKGROUND

In Sweden 4 845 609 passenger vehicles were registered in 2017 and 379 315 new vehicles were purchased [1], of which 236 546 (62%) were purchased by legal entities. Private cars are large contributors to CO_2 emissions [2, 3]. Crashworthiness and crash avoiding techniques for personal vehicles are crucial interventions to reduce accidents with serious or fatal outcome [4-6].

New vehicles have environmental and safety performances that will influence the number of road casualties and the environment for many years ahead, in average18 years in Sweden [7]. Although vehicle safety is generally a high priority for private buyers and fleet managers in Sweden compared to e.g. Spain [8], vehicle safety is not the most prioritized factor. On the other hand, consumers who focus on safety may need some guidance among all safety systems that may appear in new vehicles. A well founded vehicle safety policy may guide consumers to choose the safest vehicle, even if safety is prioritized by the consumer. Investigations show that there is a need to continuously improve understanding of what safety means to consumers and policy makers [9].

Consumer test programs such as Euro NCAP are important in the way that they put focus on the best practice in vehicle safety. However, the fitment of specific safety equipment varies between countries. A policy with detailed safety criteria is therefore important in order to guide vehicle buyers to a specific model version with desirable safety equipment.

Governmental incentives provide one way for long-term guidance towards vehicles with less CO_2 emissions [10]. However, a buyer needs to find the specific vehicles that are affected by the incentives. A vehicle policy with continuously updated emission criteria also helps to guide towards long-term emission targets and to point out the specific vehicle models with high occupant safety and low emissions.

Vehicle purchase policies used by large fleet purchasers such as companies and local authorities are important to guide towards safe and low emission vehicles [11, 12]. There is however a risk that those policies will quickly become inadequate due to rapid changes both regarding vehicle safety and emission standards. This paper illustrates the speed at which new safety systems are introduced and how difficult it is to predict. The speed of vehicle industry capability to reduce CO_2 has also been difficult to predict. Many CO_2 emission policies in Sweden has until recently used a definition of an environmentally friendly vehicle based on a state definition from 2013. This definition classified vehicles with CO_2 emissions below 120g/km as environmentally friendly. From 2018 this definition does no longer exist and there is a confusion within companies and local authorities how to define future CO_2 emission policies.

The paper aimed to show the development of the Folksam company car policy since the introduction 20 years ago and to describe the outcome of the 2019 year policy.

THE FOLKSAM VEHICLE PURCHASE POLICY

In 1997 the Folksam Group took a decision to adapt a company car policy consisting of vehicle safety and environmental requirements for vehicle transports within the company. The policy should contain tough requirements both regarding vehicle safety and CO_2 emissions. The policy criteria should be continuously improved with an annual revision regarding long-term goals but also to mirror continuous improvements in safety and emissions of the vehicle models for sale. The policy should also be supplemented with a vehicle list.

This decision also led to a guideline for rental cars used in the claims handling process at Folksam. In 2001 the policy was complemented with a vehicle list of models fulfilling the policy requirements.

Vehicles must fulfill criteria with respect to vehicle crashworthiness, fitment of safety assist systems and CO_2 emissions. An overall goal with the policy requirements was to select approximately 15% of the models for sale (in at least one version). The CO_2 emission requirement should at least be adapted to the European environmental goals [13].

The requirements in the Folksam company car policy have continuously been adapted to the developments in vehicle safety and CO_2 emissions since the introduction of the policy in 1998. In the beginning of 1998 the safety criteria consisted of crashworthiness requirements, limitations of curb weight, fitment of airbag, seat belt pretension, three point belt and head rest. The crashworthiness requirements were based on the Euro NCAP ratings and on the Folksam car model safety ratings ("How safe is your car?") based on real-world crash data [14]. The use of Euro NCAP as a predictor of performance in real-world crashes has been verified in several studies, see for example [15-17].

The environmental criteria was initially covering fuel consumption based on vehicle size (the vehicle size was defined by a classification of exterior measures [9]) and diesel fuel was initially not approved due to high levels of NO_x and PM.

DEVELOPMENTS OF THE POLICY SINCE 1998

Two different databases have been used during the years containing data from new vehicles during the period 1998-2019. Between 1998-2013 data were used from a Swedish vehicle database "Bilfakta-Bisnode" and since 2014 the vehicle data has been provided by Jato Dynamics Ltd [18]. The vehicle data cover the current status of all new vehicle models for sale in Sweden. Every six months the vehicle list is updated with new models.

Developments of safety requirements

In 1998 the requirements regarding crash safety was that the vehicle should have least a three stars in the Euro NCAP rating or shown to be at least 20% better than average in the Folksam car model safety ratings. The requirements have been continuously harder during the years, see Table 1. In recent years top results in either Euro NCAP or Folksam ratings are required. In the late 1990s whiplash research [19, 20] led to additional criteria regarding whiplash protection. The whiplash protection has been shown by Folksam, IIWPG or Euro NCAP results. During the period 2005-2016, when IIWPG whiplash rating were used, 22(16 %) of 134 tested vehicle models in 2005 were "good" compared to 79 (75%) in 2016. Table 1 shows how the various safety criteria have been gradually changed in the policy since 1998.

Table 1.
Safety criteria 1998-2019

	Crashworthiness						Seat belt				Whiplash						Safety assist				
Policy Year	How Safe is your Car	NCAP Star	NCAP Adult pt.	NCAP Pedestr pt.	Curb weight kg	Airbag driver	Pret front	3-p belt	Seat belt reminder	Head rest	Active head rest	Folksam test	IIWPG rating	NCAP rating	IIHS Dynamic rating	ESC	AEB City	AEB Urban	AEB pedestrian	LDW
1998	≥20%	≥3			1000-1600	Std	Std	Std		Std										
1999	≥20%	≥3			1000-1600	Std	Std	Std		Std										
2000	≥20%	≥3			1000-1600	Std	Std	Std		Std	Std									
2001	≥20%	≥3			1000-	Std	Std	Std		Std	Std									
2002	≥20%	≥3			1000-	Std	Std	Std		Std	Std									
2003	≥20%	≥4				Std	Std	Std		Std	Std									
2004	≥20%	≥4				Std	Std	Std		Std	Std									
2005	≥20%	≥4				Std	Std	Std		Std	Std	≤7,4p	A/G							
2006	≥20%	5				Std	Std	Std	≥1p	Std	Std	≤7,4p	A/G			Std				
2007	≥20%	5			-1900	Std	Std	Std	≥1p	Std	Std	Yellow/Green	A/G			Std				
2008	≥20%	5			-1900	Std	Std	Std	≥1p	Std	Std	Yellow/Green	A/G			Std				
2009	≥20%	5			-1900				≥1p		Std	Yellow/Green	A/G			Std				
2010	≥20%	5			-1900				≥1p		Std	Green	G	≥3p		Std				
2011	≥30%		≥88%	≥40%	-1900				≥2p			Green	G	≥3p		Std				
2012	≥30%		≥88%	≥40%	-1900				≥2p			Green	G	≥3p		Std				
2013	≥40%		≥88%	≥40%	-1900				≥2p				G	≥3p		Std				
2014	≥40%		≥88%	≥40%	-1900				≥2p				G	≥3p		Std				
2015	≥40%		≥88%	≥40%	-1900				≥2p				G	≥3p		Std				
2016	≥40%	5							≥2p				G	≥3p		Std	Std/opt			
2017	≥40%	5							≥2p				-	≥3p		Std	Std/opt			
2018	≥40%	5							≥2p				-	≥3p		Std	Std	Std		
2019	≥40%	5							≥2p				-	≥3p/G	G	Std	Std	Std	Std/opt	Std/opt

The crashworthiness of the vast majority of new vehicles has during the years been verified by Euro NCAP results. Rating results from real-world crash data has only been available for a smaller number of vehicles. Figure 1 shows the distribution of Euro NCAP stars for all new vehicles in Sweden 2019. 157 (58%) of 270 new vehicles available of model year 2019, have a five-star rating. 66 (24%) were either not tested or tested prior to 2012. In 2001, when the vehicle policy was complemented with a vehicle list, Euro NCAP data from 89 new vehicle were evaluated of which only one model received five stars and 42 (47%) received four stars. In 2001 the requirements for superminis and small family cars was that they should have at least four stars and for large family cars and executive cars that they should have at least three stars in Euro NCAP.

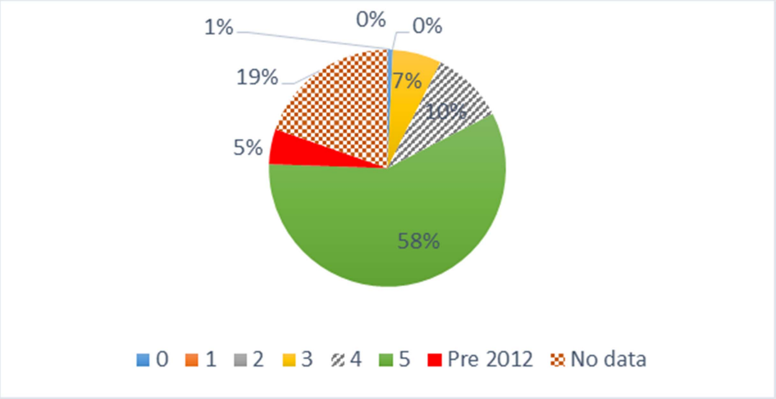

Figure 1. Euro NCAP star 1997-2019

Safety systems

Requirements regarding fitment of new effective safety technologies have been introduced continuously, see Table 1. In 2006 fitment of Electronic Stability Control (ESC) was introduced as a requirement (Table 1) and 82(32%) vehicle models have had ESC as standard on all versions and reached 80% in 2009 and 100% in 2017.

In 2016 fitment of Autonomous Emergency Braking (AEB) was introduced as a requirement (see Table 1). In 2016, AEB City (all versions with 100% fitment) was available in 24% of vehicle models (see Table 2). In comparison 59% of sold models have had AEB City 2016 (see Table 2). It is shown in Table 2 that 76% of vehicle models in 2016 have had AEB city as standard, option or not available, depending on the model version. A higher rate of safety assist systems in sold models compared to models for sale can be seen in Table 2-4. The implementation of AEB interurban, and AEB with detection of vulnerable road users (VRU) is not as fast as for the AEB city. For AEB interurban, 26% of all models with standard fitment was reached in 2017 (see Table 3). Standard fitment of AEB with VRU detection reached 22% in 2017 (see Table 4). In 2018 the proportion of vehicle models with standard fitment of AEB Interurban was 42% and for AEB VRU it was 37%, which was lower than for AEB city (59%). The number of sold vehicle models with standard fitment of AEB of all types, has increased more rapidly than the fitment rate in the models for sale. The rate of sold vehicle models 2017 with standard fitted AEB with VRU detection was 45% lower than for AEB city.

In 2019 also AEB with detection of VRU was introduced as a requirement (see Table 1). This is a result of real-world results indicating a good safety performance [21] [22] together with the rapid implementation of this system since 2014 (see Table 4).

Standard fitment of Lane departure warning (LDW) is not as common as AEB city/interurban, neither for vehicle models for sale or for sold vehicles. In 2018 29% of vehicle models had LDW as standard fitment (see Table 5). LDW was introduced as a requirement in 2019 (see Table 1) as a consequence of studies indicating good safety performance [6, 23].

Table 2.
City AEB – fitment/sold models

		2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
100% Std	Fitment	5,0%	5,0%	8,0%	15,9%	23,6%	38,0%	58,7%
	Sold	18,0%	26,0%	30,0%	50,8%	58,6%	69,0%	No data
Std/Opt/Not available	Fitment	6,0%	5,0%	5,0%	10,5%	11,1%	14,8%	4,2%
	Sold	5,0%	2,0%	7,0%	3,6%	19,8%	12,0%	No data
100% Option	Fitment	12,0%	15,0%	21,0%	13,2%	13,2%	11,8%	12,5%
	Sold	20,0%	25,0%	23,0%	15,2%	9,6%	9,0%	No data
100% Not available t	Fitment	77,0%	75,0%	66,0%	60,3%	52,0%	35,4%	24,7%
	Sold	57,0%	47,0%	40,0%	30,4%	12,0%	10,0%	No data

Table 3.
Interurban AEB – fitment/sold models

		2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
100% Std	Fitment	0,0%	0,0%	3,0%	8,5%	11,6%	25,5%	42,4%
	Sold	0,0%	0,0%	7,0%	17,8%	24,4%	59,0%	No data
Std/Opt/ Not available	Fitment	5,0%	5,0%	7,0%	8,8%	13,3%	10,3%	2,8%
	Sold	10,0%	9,0%	15,0%	12,3%	23,2%	9,0%	No data
100% Option	Fitment	5,0%	8,0%	12,0%	12,2%	12,3%	10,7%	12,5%
	Sold	10,0%	13,0%	25,0%	20,7%	19,1%	12,0%	No data
100% Not available	Fitment	90,0%	85,0%	78,0%	70,5%	62,8%	53,5%	42,4%
	Sold	80,0%	78,0%	53,0%	47,9%	33,4%	20,0%	No data

Table 4.
AEB VRU detection – fitment/sold models

		2012	2013	2014	2015	2016	2017	2018
100% Std	Fitment	0,0%	0,0%	2,0%	5,0%	12,0%	22,1%	36,8%
	Sold	0,0%	0,0%	4,0%	12,0%	20,0%	38,0%	No data
Std/Opt/ Not available	Fitment	0,0%	0,0%	1,0%	3,0%	5,0%	1,5%	1,7%
	Sold	0,0%	0,0%	4,0%	6,0%	10,0%	17,0%	No data
100% Option	Fitment	3,0%	3,0%	5,0%	6,0%	7,0%	8,1%	10,4%
	Sold	6,0%	6,0%	10,0%	12,0%	14,0%	11,0%	No data
100% Not available	Fitment	97,0%	97,3%	92,0%	86,0%	76,0%	68,3%	51,0%
	Sold	94,0%	94,0%	82,0%	70,0%	56,0%	34,0%	No data

Table 5.
LDW fitment models

Fitment	2016	2017	2018
100%Std	7,1%	20,7%	28,8%
Std/Option/ Not available	29,2%	25,4%	25,7%
100% Option	18,6%	17,3%	17,7%
100% Not available	45,2%	36,6%	27,8%
Sum	100,0%	100,0%	100,0%

Emission criteria

The CO_2 emission requirements in 1998-2012 were divided for various vehicle size groups. From 2013-2019 this criterion was changed to emission level by curb weight. To be able to present the emission figures from 1998-2019 with respect to vehicle size in this paper, the average curb weight was calculated for each vehicle size and model year and associated emission figures are presented (see Table 5-8).

During 1998-2002 vehicles with diesel engines were not allowed in the policy. In 2003-2012 diesel engines needed to have a 20% lower fuel consumption than petrol to fulfill the emission criteria. Since 2013 the CO_2 emission criteria were equal for diesel and petrol.

The CO_2 emission requirements have been tightened during 1998-2019. Table 5 presents the CO_2 limits for petrol vehicles in the vehicle policy, showing a reduction in emission level of 47-50% between 1998 and 2019.

Table 5.
CO_2 emission limit petrol 1998-2019

Policy year	CO_2 g/km Super mini	CO_2 g/km Small family car	CO_2 g/km Large family car	CO_2 g/km Executive car
1998	186	186	205	231
1999	182	182	201	227
2000	151	177	196	222
2001	149	175	194	219
2002	146	172	191	215
2003	144	168	186	210
2004	139	163	182	205
2005	139	163	182	205
2006	139	158	179	201
2007	137	156	175	196
2008	132	153	170	191
2009	130	151	168	189
2010	127	149	165	184
2011	125	146	158	177
2012	123	142	151	170
2013	112	120	126	139
2014	105	105	113	126
2015	105	105	109	120

2016	105	105	110	120
2017	104	104	109	118
2018	99	99	108	116
2019	99	99	108	115
Change (%)	-46,9	-46,9	-47,6	-50,1

Table 7 shows the reduction of CO_2 emission limit during 16 years. For smaller family cars a 36% reduction can be seen and for large vehicles a 39% reduction.

Table 7.
CO_2 emission limit diesel 2003-2019

Policy year	**CO_2 g/km Super mini**	**CO_2 g/km Small family car**	**CO_2 g/km Large family car**	**CO_2 g/km Executive car**
2003	131	152	168	189
2004	125	147	165	187
2005	125	147	165	187
2006	125	144	163	181
2007	123	144	160	179
2008	120	141	157	173
2009	120	139	155	171
2010	120	136	152	168
2011	123	133	149	163
2012	123	133	147	157
2013	112	120	126	139
2014	96	105	113	126
2015	88	101	109	120
2016	90	102	110	120
2017	88	101	109	118
2018	89	99	108	116
2019	90	98	108	115
Change (%) 2003-2019	31,3	35,5	35,7	39,1

THE FOLKSAM VEHICLE PURCHASE POLICY 2019

Safety criteria

The vehicle crash worthiness was verified either from the Folksam car model safety ratings [24] or from vehicle safety ratings from Euro NCAP results. The car must be at least 40% better than average in the Folksam ratings or receiving a five star rating in Euro NCAP. Since the Euro NCAP test protocol continuously undergoes changes, older test results than 2012 was not accepted in the 2019 years requirements of the policy.

To reach top score in Euro NCAP, specific safety equipment needs to be available on the test vehicle. Since the availability varies for different markets, it was a need to have additional requirements for important safety systems. The safety systems required in the policy are shown in Table 1.

Table 1. Required safety systems in Folksam vehicle policy

Safety system	**Availability**
AEB (Autonomous Emergency Braking)	Standard
AEB VRU (AEB with detection of vulnerable road user)	Standard or option
LDW (Lane Departure Warning)	Standard or option
ESC (Electronic Stability Control)	Standard

The level of whiplash protection was also included in the safety requirements verified through whiplash rear impact score in Euro NCAP. The whiplash score for the front seats had to be “Green”. As an alternative, the dynamic rating in “Head restraint & seats” published by IIHS was used [25]. The dynamic rating score had to be “Good”.

Emission criteria

The current emission criteria for 2019, was adapted to reach the European targets of CO_2 emission [13]. However, the long-term goal is to reach net zero emission of new vehicles by 2030 [26].

The 2019 year revision of the policy consists of two levels of CO_2-emissions. Until 2019 the assessed CO_2 emissions have been based on the driving cycle NEDC (New European Driving Cycle). Since September 1st 2017, a new driving cycle, WLTP (Worldwide Harmonized Light Vehicle Test Procedure) was introduced and became mandatory for vehicles launched September 1st 2018 and onwards. During 2019 two CO_2 emissions figures will appear for new vehicles, NEDC values or NEDC corr values. NEDC corr was used as a transition to WLTP and was calculated from the WLTP value. From 2020 only WLTP will be used.

The emission criteria are illustrated in Figure 3. The CO_2 emission value are related to the vehicle curb weight. NEDC emission limits start at 99 g/km and ends at 110 g/km. NEDC corr emission limits is higher to correspond to the differences between NEDC and NEDC corr values. The limit starts at 108 g/km and ends at 121g/km.

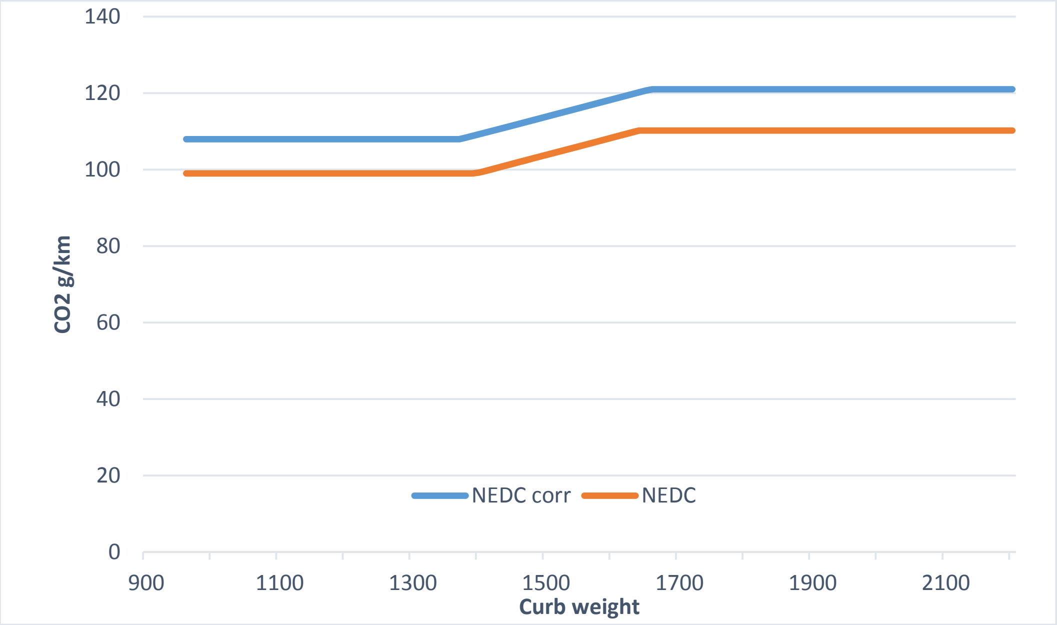

Figure 2. Emission criteria

The difference of emission values between NEDC and NEDC corr were evaluated from an analysis of 1253 vehicle model versions with model year 2017, identical to current versions (see Figure 3). The analysis shows that 75% of the observed versions had an increase of CO_2 from NEDC to NEDC corr of 0-20 g/km. The difference in emission between NEDC and NEDC corr was also shown to be larger for larger vehicles in general. This is the reason for the difference of 9-11 grams between NEDC and NEDC corr CO_2 limits (see Figure 2).

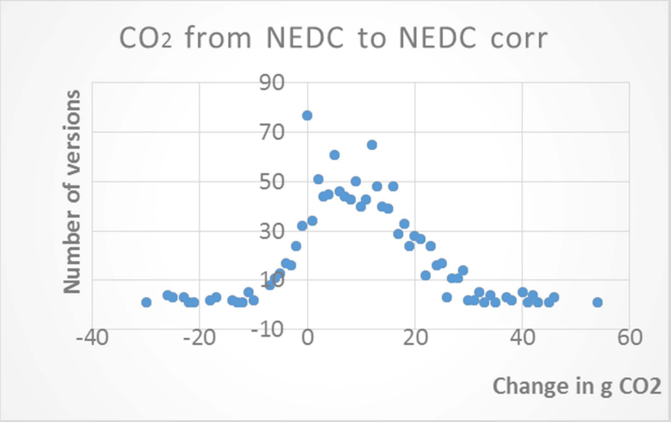

Figure 3. Number of model versions with changed CO_2 emission values from NEDC to NEDC corr

Out of 270 new vehicle models of model year 2019, 44 models (16%) fulfilled the requirements in the policy. In total 44 out of the 270 available models fulfilled the requirements of the 2019 revision of the policy (see Table 9). The listed models have at least one version that fulfills the policy requirements. In total 206 versions of these models fulfilled the requirements (see Table 10). Only a few superminis, large MPVs and Large SUVs can be seen in Table 9 and 10, showing that these size categories have lower specifications regarding safety and/or higher CO_2 emissions.

Table 9.
Number of models with at least one approved version vs. models without any approved version

Size	Models fulfilling the requirements	Models without any version approved	Total
Super mini	1	32	33
Small family car	8	52	60
Large family car	13	24	37
Executive car	8	26	34
Small MPV	5	8	13
Large MPV	0	12	12
Small SUV	8	35	43
Large SUV	1	37	38
Total	44	226	270

Table 10.
Number of model versions approved/failed

Size	Versions approved	Versions failed	Total
Super mini	10	207	217
Small family car	27	517	544
Large family car	90	584	674
Executive car	40	603	643
Small MPV	6	78	84
Large MPV	0	135	135
Small SUV	28	468	496
Large SUV	5	462	467
Total	206	3054	3260

The vast majority of the vehicle models fulfilling the criteria (23) are models with diesel engines. Only three models have pure petrol engines. Nine models have at least one electric hybrid version. Thirteen models have at least one plug-in hybrid version. Six pure electrical vehicle models are among the ones fulfilling the policy requirements. Two models with CNG (Compressed Natural Gas) and one model with fuel cell also fulfill the policy requirements 2019.

DISCUSSIONS

It is important to guide vehicle fleet buyers of personal vehicles to choose the most safe and environmentally friendly vehicles since those vehicles will be used for many years. It is also important that the requirements follow the developments in vehicle safety and that they are in line with the global emission targets.

One of the purposes with a vehicle purchase policy is to speed up the implementation rate of important safety technologies. One example of a fast implementation in Sweden is the introduction of ESC [27]. ESC only had 15% market penetration in the 2003, but after five years the fitment rate was above 90%. Since 2009 the increase has been slow, but in 2017 the fitment rate of ESC in Sweden was 100%. ESC has been included in the Folksam policy since 2006. However, in the 2020 revision of the policy it might be excluded.

Other safety technologies that have been introduced and that have increased their implementation rate is various kinds of AEB and LDW. Many of these technologies have a more than 50% fitment rate of sold cars in 2019. In Table 2, 76% of the vehicle models have AEB City as standard, option or not depending on model version. The vehicle policy guides the consumer to find vehicle models fitted with those safety systems, but it also influence the vehicle manufacturers to make the important safety systems as standard fitment. This is important because fleet purchasers or private consumers often have difficulties to identify which of the safety features that are of importance for safety. An example is ABS, that has been shown to be less effective [28, 29] in contrast to for example AEB or lane departure system that have been shown to be effective[4, 6].

Table 2-4 show differences in fitment rates between vehicle models for sale and sold models. There are probably several reasons for this. In Sweden there is a lot of communications towards vehicle consumers that e.g. AEB is an important feature so customers are aware of its importance. Several car fleet purchasers also include safety requirements in their purchase policies. It is not surprising that sold vehicles have a higher safety standard compared to the models for sale.

During the last two decades limitations in curb weight have been included in the requirements. Studies of vehicle compatibility shows that there is a need to limit the large variation in curb weight [5, 30-32]. The upper limitation of 1900kg was previously included in the Folksam policy as a result of this knowledge[33]. There is however a development towards a larger spread in curb weight. Small vehicles becomes heavier but new smaller vehicle segments appear. It is still 11 new vehicle models of model year 2019 in the database, which has a curb weight below 1000kg. At the same time there are 45 vehicle models with curb weight over 2000kg in the database. 16 of those heavier vehicle models are supported by electrical motors. In conclusion there will be a need for a curb weight limitation in the policy criteria that does not exclude new environmentally friendly engine techniques.

The list of model presented in Table 9 shows that only a few models of the vehicle categories superminis, large MPVs and Large SUVs fulfill the requirements. The main reason for the superminis to fail is the absence of AEB with pedestrian detection. The large MPVs most commonly fail due to large emissions but also lack of AEB with pedestrian detection. MPVs are not usually fitted with alternative fuels such as batteries. The large SUVs fail most often due to large emissions.

The emission requirement contains only limits regarding CO_2. The emission of CO_2 is crucial for the climate change and historically diesel engines has had lower CO_2 emissions compared to petrol engines. However emission of NOx, especially from diesel engines, is also a health problem, especially in dense cities [34]. There is a need to control the NOx emission as well since investigation of real emissions is shown to be extensively higher than the emission level defined by Euro 6. In the transition period to alternative fuels, diesel and petrol will be used. The RDE (Real Driving Emission) which is included in the WLTP test cycle from 2017, measures NOx emitted by the vehicles while driven on the road [35]. This will probably control the NOx emission and will mean that requirements for NO_x emission does not need to be included in the policy.

There is an increasing interest of more fuel saving vehicles and vehicles that can be driven fossil free. Fuel economy is one of top three purchase criteria which makes PHEV vehicles and electrical cars of special interest for car buyers [36]. The number of plug-in hybrids for sale is increasing. However, there are relatively few plug-in hybrids in the policy list 2019. One reason is the change from the emission driving cycle NEDC to WLTP. A large number of plug-in hybrids has not been tested according to WLTP and will therefore need to wait until the WLTP test is done.

CONCLUSIONS

It is important to guide vehicle fleet buyers of vehicles for private use to choose the safest and most environmentally friendly vehicles since those vehicles will be used for many years. Company car policies are important tools in this process. A vehicle purchase policy will indirectly influence car manufactures to offer vehicles that fulfil the requirements in the policy.

An important recommendation is that a vehicle purchase policy should be revised annually to follow rapid changes in available safety technology and emission standards in order to substantially influence the vehicle fleet. A vehicle purchase policy is an important tool to guide vehicle consumers towards the safest and most sustainable vehicles. It is recommended that a vehicle purchase policy should consist of requirements regarding crashworthiness, fitment of important safety systems, CO_2 emissions. Preferably, it should be complemented with a vehicle list for tangible and feasible advice to consumers

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IMPROVEMENTS TO ASEAN NCAP CRASH TEST RATING SANS A PLATFORM CHANGE

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ABSTRACT

Besides other reasons, car manufacturers often develop new cars with the aim to improve on their ASEAN NCAP crash safety performance rating. Apart from car safety assist, such ratings depend on the degree of adult occupant protection (AOP) and child occupant protection (COP) measured via the seriousness of injuries to dummies. This study shall explain how car manufacturers can improve their crash performance rating without changing the platform structure of a new car. The move shall be more cost effective as platform structure development is expensive; and less time consuming to enable a product to be launched in time (Al-zaher & Elmaraghy, 2014; Al-zaher & Elmaraghy, 2014). Two ASEAN NCAP crash tests have been conducted on 2 car brands on two different occasions, with the more recent result showing improvement from 3-Star to 4-Star rating. This proves that without a platform structure change, a high rating can still be achieved. Such a situation will help manufacturers save cost and reduce time to develop a new car by using the same platform structure but with better safety performance.

INTRODUCTION

An important element of any car is the body structure or platform [1]. The platform connects all the different components; whereby it houses the drive train and more importantly carries and protects passengers and cargo. The body structure needs to be rigid to support weight and stress and to securely tie all the components [2]. Furthermore, it must resist and soften the impact of a crash to safely protect the occupants. Thus, most automobile manufacturers seek to design better automobile structure to ensure passenger safety as well as reduce the automobile mass [3].

ASEAN NCAP Safety Star Rating *vis-a-vis* or pertaining to a car body structure focuses more on passive safety whereby tests are carried out to assess frontal and side impacts. Nonetheless, the regulations in regard to these assessments have become more stringent in the past decade. Many automobile industries are therefore aiming to design better platform structure for passenger safety as well as to reduce platform mass [4]. Better platform structure will hopefully enhance passive safety and a good body structure base will possibly result in better crash performance. It is important to note that a good crash performance is achieved by way of impact energy absorption [2]. In other words, how impact energy is absorbed will affect the severity of passenger physical injuries as well as damage to the car interior [5]. The less injury a passenger dummy suffers, the higher the structure performance is rated.

All passenger cars are built on platforms or architectures defining the core engineering of a vehicle. Traditionally, automotive OEMs have shared this engineering across products. For example, under the hood, Skoda Fabia and Volkswagen Polo use the same engineering structure. As platform development accounts for nearly half of the product development cost borne by Original Equipment Manufacturers (OEMs), the strategy of using common engineering across vehicle models have enabled them to cut cost as well as save time [6]. If the industry can create one good platform to enhance crash performance and use this method of sharing, there will be an increase of safer cars on the market and more lives can be saved as a consequence of a reduced passenger injury. This paper shall highlight that with some enhancements made to new car *sans* or without a platform change, it is possible to improve their ASEAN NCAP rating from 3-Star to 4-Star.

PLATFORM STRUCTURE

A vehicle frame, which is also called chassis, is the main supporting structure of a motor vehicle to which all other components are attached. Most car models and even car types share a set of common design, engineering, production efforts, as well as major components [7]. This practice is a norm in the automotive industry to reduce the cost associated with product development by basing several products on a smaller number of platforms [8]. This further allows companies to create distinct models from a similar design perspective.

As mentioned earlier, ASEAN NCAP Star Rating for platform structure is conducted via the frontal crash and side impact barrier crash tests. The detail calculation is based on (i) injuries suffered by a dummy's head, chest, knees, tibia, and foot during a crash test and (ii) the car body structure (also known as modifiers). For the frontal impact against offset deformable barrier (ODB) with 40 % overlap at 64 km/h, the structure rating will divided into two parts, namely the upper occupant compartment and lower occupant compartment. In addition, for side impact mobile deformable barrier (MDB) at 50 km/h, scores will only be calculated for rating purposes.

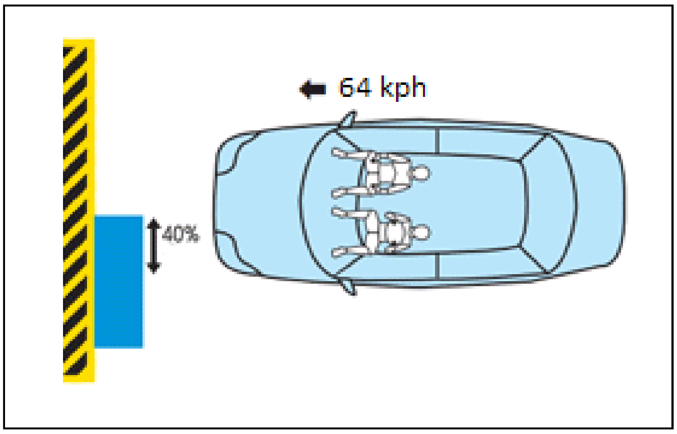


Figure 1. Example of frontal impact 40% ODB

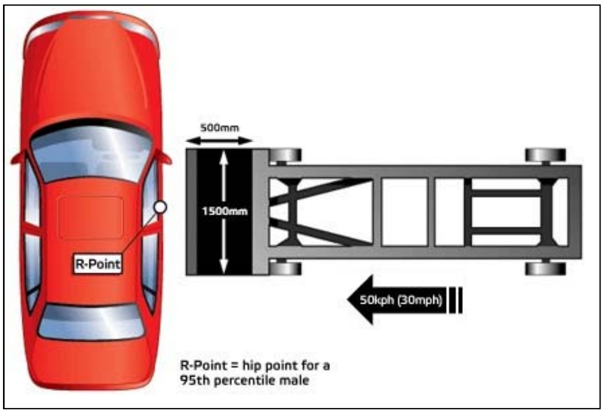
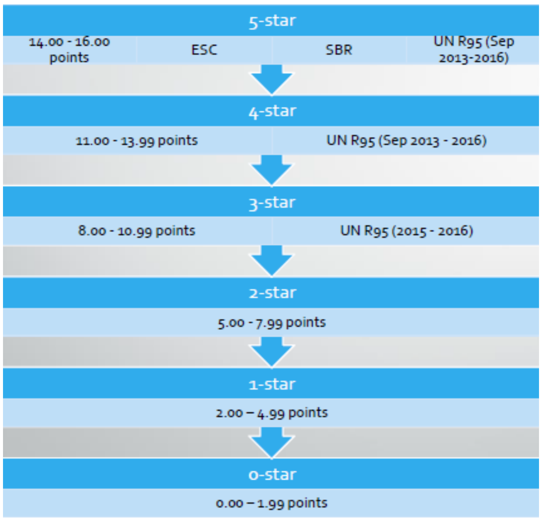
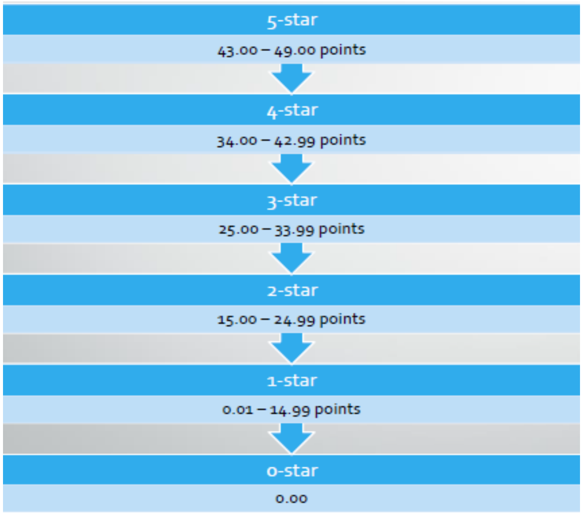


Figure 2. Example of side impact MDB

CASE STUDY

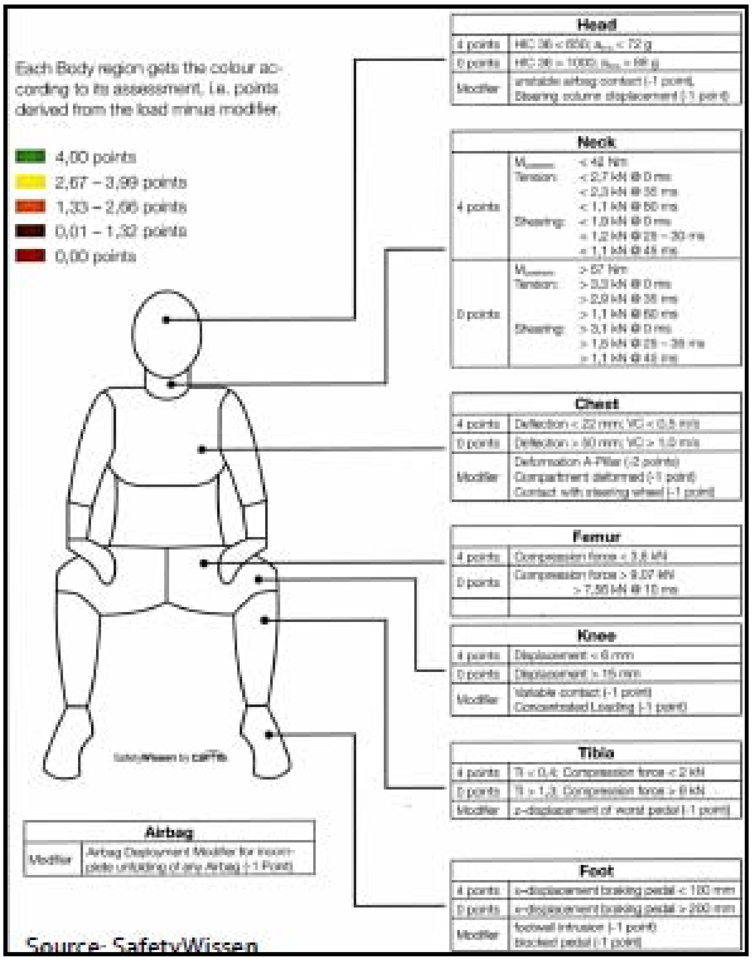
ASEAN NCAP rating calculation is divided into three categories, which are AOP, COP and safety assist. Each category has different calculations and will affect the overall Star Rating [9]. Table 1 below shows AOP rating and COP rating from 5-Star to 0-Star based on ASEAN NCAP protocol 2012-2016.

Table 1.
Rating protocol based on protocol 2012-2016

Adult occupant protection (AOP) Rating	Child occupant protection (COP) Rating
	

The entire Star Rating is based on the frontal crash and side impact crash tests. Both crashes use P1.5 and P3 dummies to represent children and hybrid III 50% dummies for adults. In the frontal crash, a car will impact the 40% OBD (Offset-Deformable Barrier) at a travelling speed of 64 km/h. As for the side impact test, a car occupied by ES-2 dummy will be impacted with MDB EEVC (Mobile deformable barrier European Enhanced Vehicle-safety committee) (900kg) at a travelling speed of 50km/h. For AOP assessment, results of the frontal crash impact will be calculated in terms of the injury suffered by the dummies and the car structure modifier. Figure 3 shows the division of points for AOP dummy injury. Further, COP also looks at inclusion of CRS (child restrain seat), as well as vehicle-based test and dynamic test to obtain the highest score of 49.00 points.

This testifies that the main contributor to the points in determining ASEAN NCAP Star Rating is the injury to the dummies. The less the injury to the dummies, the higher Star Rating shall be awarded. Further, crash test impact is conducted to determine the level of strength and impact energy absorption of a vehicle [10]. In order to reduce injury of the dummies upon impact, automotive manufacturers need to improve passive safety technology which shall in turn elevate their ASEAN NCAP rating. To enhance passive safety capability, it is not necessary to change the platform structure because in the past, ASEAN NCAP has seen two car brands which had successfully upgraded their rating without changing their original platform structure [11]. Such a feat was achieved by adding strength to the platform structure and upgrading some components in both cars.



Source- SafetyWissen

Figure 3. Example AOP Calculation Point

HISTORY OF ASEAN NCAP RATING UPGRADE

Vehicle brand 1

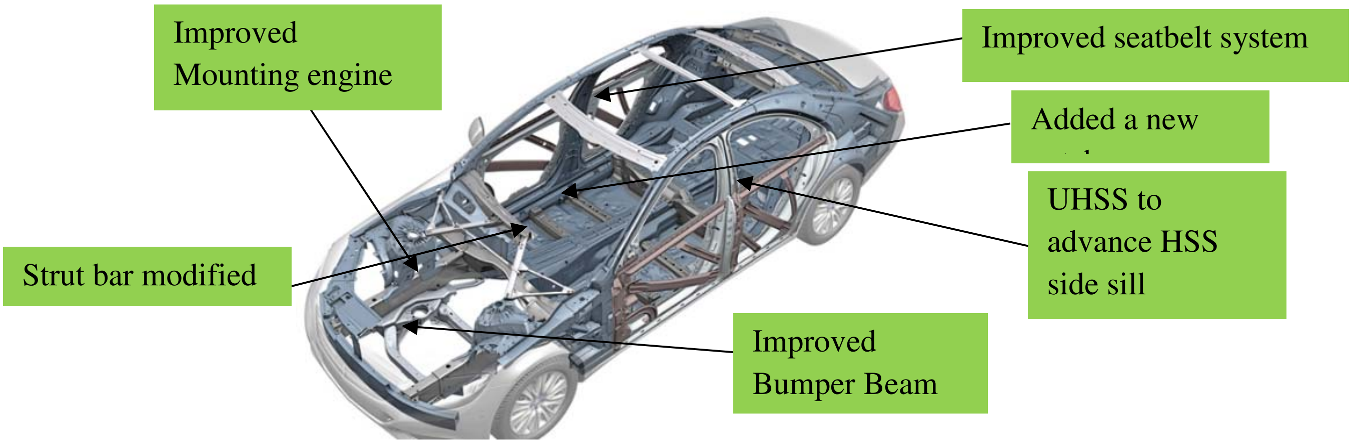
As per its background, Vehicle 1 is categorized as a 4-door sedan of the same variant and platform but with different engine capacity and kerb mass. In order for the manufacturer to use the platform for a new car but with better safety, some upgrading works had to be done. The result of the first crash test was 3-Star, but following some upgrading to the body structure, the rating improved to 4-Star upon being re-crashed. The gap between both crash tests was 3 years. The upgrading carried out is as shown below:

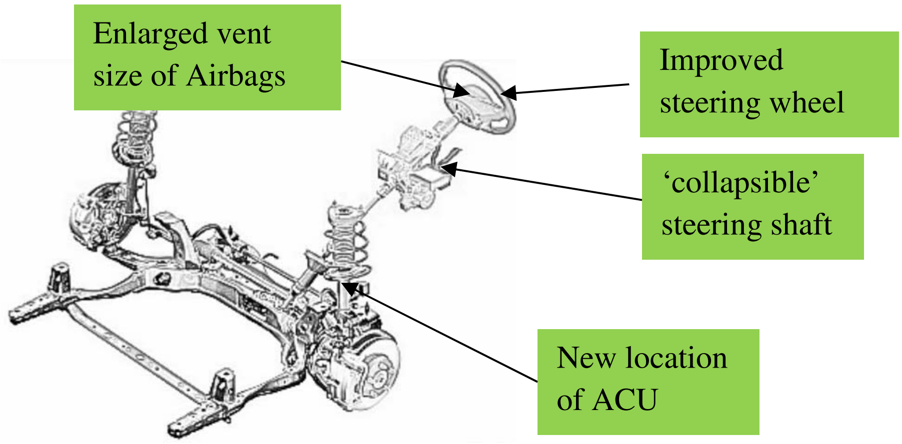
Body structure improvements

- Improved Bumper beam area
- Improved Mounting engine
- At driver and passenger area of leg to knee - changed from UHSS to advance HSS side sill
- Strut bar added
- Improved seatbelt system
- Adding of patch car floor

Component structure system upgrading

- Improved the 'collapsible' steering shaft
- Upgraded steering wheel
- Enlarged size of vent DAB and PAB
- ACU position changed to more strategic location





The first crash test was in 2013, and following a lot of changes and upgrading, the second crash test for Vehicle 1 registered an improvement in terms of its safety features where it achieved 13.33 over 16.00 points in the AOP, thus placing it in the 4-Star category. Compared to the previous test, Vehicle 1 was awarded 10.23 points with 3-Star rating for its AOP.

As for the COP, Vehicle 1 recorded a commendable achievement by obtaining 71% compliance, which was within 4-Star rating. Vehicle 1 comes with standard dual airbags and Seatbelt Reminder System (SBR) for driver only. Furthermore, Vehicle 1 is equipped with standard ISOFIX and top tether. However, Anti-lock Braking System (ABS) is not available in all variants while Electronic Stability Control (ESC) can only be found in the premium variant.

Vehicle brand 2

As per the background, Vehicle 2 is categorized as a 5-door hatchback of the same variant with the same platform and engine capacity but different kerb mass. In order for the manufacturer to use the same platform structure for a new car with better safety, some upgrading works had to be done. In the first crash test, Vehicle 2 was awarded 3-Star, but upon improvements to the body structure, it was awarded 4-Star after being re-crashed. The gap between the first and second crash tests was 2 years. The upgrading carried out is as shown below:

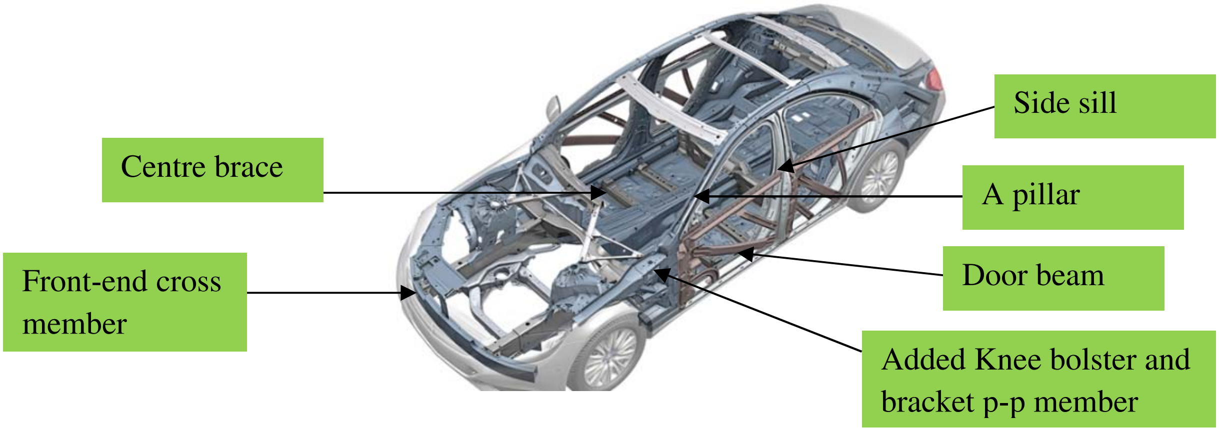
Body structure (improved to prevent cabin and body deformation)

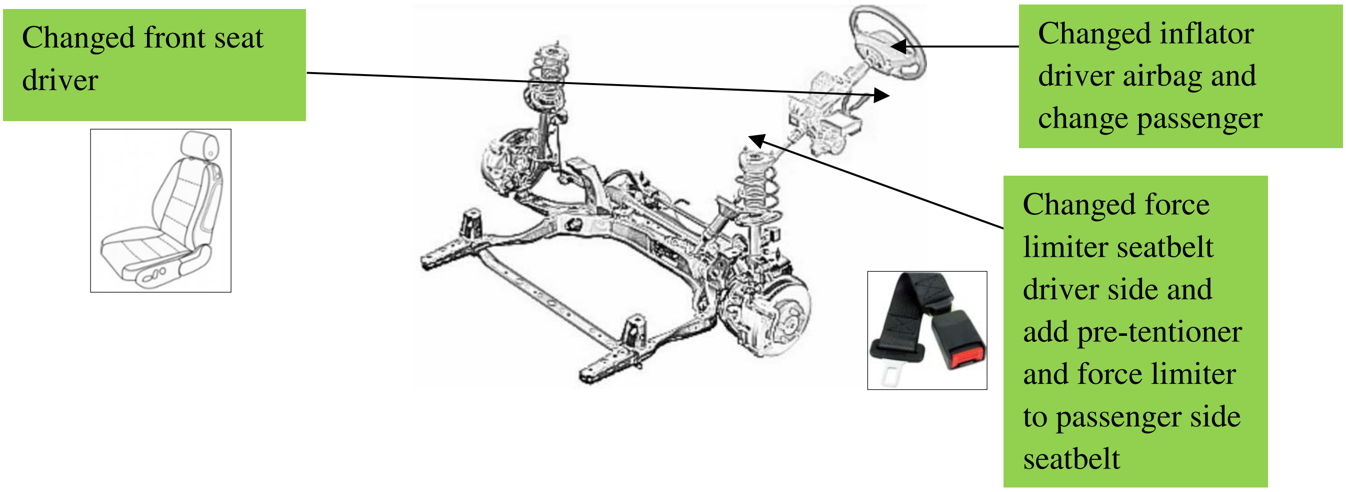
- Door beam
- A pillar
- Side sills
- Centre brace

- Front-end cross member

Passenger restraint

- Improved quality of airbag
- Improved material of seatbelt
- Additional Knee bolster
- Additional bracket P-P member
- Changed front seat driver
- Changed inflator driver airbag
- Changed passenger airbag





Upon making some changes to the body structure and passenger restraint, Vehicle 2 latest version (crash tested in 2015) obtained 4-Star in AOP with 11.55 points. In comparison, it was awarded 3-Star AOP with 8.71 points in 2013. Vehicle 2, which is the all time best selling model in Malaysia has also improved its score in COP with 71 % compared to 54% in the first crash test. It is therefore rated 4-Star. As per the child restraint system, ISOFIX & top tether are available as standard fitment. The stability control system (ESC) is, nevertheless, only offered in higher variants.

CONCLUSION

Car manufacturers have always competed by coming up with newer cars in a bid to become the market leader. Of late, with the launch of each new model, they will make sure that aside from the aesthetic features and fuel efficiency, the safety aspects will also be taken into account. Such safety aspects are translated into high Star Rating awarded by NCAPs across the globe. At the same time, car makers must also find the most viable solution to come up with competitive products at lower costs and increased profits [12]. This study has elucidated that in order to improve crash safety performance, a manufacturer does not necessarily need to change the platform structure for a new car. ASEAN NCAP's crash test results involving Vehicle brand 1 and Vehicle brand 2 provided a clear example that a car safety performance rating can be improved without changing the platform structure. What was needed were merely several changes to the passenger restraint system, component system as well as the body structure. Furthermore, better crash performance is indicated by lower injury levels to passenger which in return raises interest among potential car buyers. Collaboration between brands to share the platform structure with good crash performance result could, at the same time, reduce the cost of producing safer new cars. But more importantly, such a practice will ensure more safer cars on the market and thereby result in safer roads.

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THE ROLE OF VEHICLE AGE IN ROAD FATALITIES AND THE COMMUNITY AWARENESS ACTIVITIES EMPLOYED TO ENCOURAGE FLEET RENEWAL AND REDUCE ROAD TRAUMA

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ABSTRACT

Following a period of steady decline in national road tolls in Australia and New Zealand, recent consecutive increases in annual road fatalities have caused community concern, with policy makers and road safety organisations working to ascertain reasons for this trend reversal.

It is well established that newer vehicles generally offer higher levels of safety when compared to older vehicles, due to technology developments and the inclusion of specific safety features, with studies based on real-world data supporting this [1,2]. Statistical studies of real world crashes often report on factors such as driver age, crash type and posted speed limit, however the involvement of vehicle age in fatal crashes is less understood.

To build a greater understanding of the age of vehicles involved in crashes occurring in Australia and New Zealand, ANCAP began monitoring the age of light passenger and sports utility vehicles involved in fatal crashes, with the findings used to inform road safety policies and community education and awareness activities.

In 2018, ANCAP developed a national community awareness campaign targeting community consideration of vehicle age with the objective of encouraging fleet renewal.

This paper sets out the research findings over the analysed five-year period from 2012-2016 and the effectiveness of the subsequent national community awareness campaign.

BACKGROUND

The Australasian New Car Assessment Program (ANCAP Safety) provides consumers with transparent advice and information on the level of occupant and pedestrian protection provided by different vehicle models in the most common types of crashes, as well as their ability - through technology - to avoid a crash. The program influences the design of new vehicles, encouraging vehicle manufacturers to offer a level of safety above that required by regulation and to continue to increase safety performance as technology develops.

CRASH DATA ANALYSIS

Method

Vehicle occupants represent the largest road user group in road fatalities each year, accounting for 66% of Australian road fatalities over the period 2012-2016 and 71% in New Zealand [3,4]. Specifically, occupants of light passenger vehicles and sports utility vehicles (SUVs) represent approximately 49% and 56% of road fatalities in Australia and New Zealand respectively over the period, while these vehicle types represent 75% and 78% of the respective vehicle fleets [5,6].

The analysis focusses on road fatalities where an occupant of a passenger car or SUV was fatally injured and compares the age distribution of those vehicles involved against the age distribution of the passenger car and SUV fleet. Other road user groups and vehicle types have not been included. Australia and New Zealand have been analysed separately due to fleet profile differences and to provide information specific to each country.

To perform the analyses, two key datasets were required:

1. Road fatality data identifying the fatality type, vehicle type and year of manufacture; and
2. Fleet data identifying the type and age of vehicles within the registered (AUS) / licensed (NZ) fleet.

Datasets for occupant fatalities occurring in light passenger vehicles and SUVs range from 500 to 700 fatalities each year in Australia and 120 to180 fatalities in New Zealand. Organising this data into groups by vehicle year of manufacture matching the information reported by the fleet statistical data allowed age comparisons to be made between vehicles involved in occupant fatalities and vehicles within the respective fleets.

Data sources

Australian fleet information was sourced from the *Motor Vehicle Census, Australia* reports published by the Australian Bureau of Statistics (ABS) [5,7-10], while New Zealand fleet information was sourced from the *New Zealand Vehicle Fleet Status* reports published by the New Zealand Ministry of Transport [11-14].

For Australia, Motor Vehicle Census reports are based on the fleet at 31 January of the report year. For the purpose of this analysis, fleet information at 31 January is considered a good representation of the fleet at the end of the previous year.

Vehicle age amongst the Australian passenger car and SUV fleet is reported in four groups based on year of manufacture. Three of these groups span five years each while the remaining group includes vehicles that are fifteen years or older. These groups roll over based on the year in which the motor vehicle census is conducted.

For New Zealand, the fleet status data is reported at 31 December. Vehicle year of manufacture is generally reported in six groups, each spanning 10 years, however these groups do not rollover and remain consistent each year. As a result, the newest group identifying vehicles built between '2010-current' continues to grow with each status report as more new vehicles are added to the fleet.

Australian road fatality data identifying the fatality type, vehicle type and year of manufacture was sourced from the Bureau of Infrastructure, Transport and Regional Economics (BITRE) National Crash Database [16]. Corresponding New Zealand data has been provided by the New Zealand Ministry of Transport and the New Zealand Transport Agency [17].

Results

Tables 1 and 2 show the age distribution amongst passenger vehicles and SUVs involved in occupant fatalities over the period 2012 to 2016. Vehicle age shown is based on the age in the year in which the crash occurred. Occupant fatalities where the vehicle year of manufacture is unknown represent 11% of the Australian dataset and less than 1% of the New Zealand dataset.

Vehicles aged 24 years or less were involved in the majority of occupant fatalities, with older vehicles, particularly those aged 30 years or more, involved in relatively few occupant fatalities. The average age of light passenger vehicles involved in occupant fatalities during the five-year period was found to 12.7 years in Australia and 16.1 years in New Zealand.

Table 1.
Occupant fatalities by vehicle age at the time of crash (2012 to 2016)

Vehicle age (years)	Occupant fatalities in Australia	Percentage	Occupant fatalities in New Zealand	Percentage
0-4	361	12%	42	6%
5-9	554	18%	79	10%
10-14	745	25%	162	22%
15-19	638	21%	259	34%
20-24	297	10%	155	21%
25-29	62	2%	44	6%
30-34	25	1%	3	0%
35-39	4	0%	3	0%
40-44	3	0%	0	0%
45-49	5	0%	2	0%
50-54	1	0%	0	0%
55-59	1	0%	0	0%
60-64	2	0%	0	0%
65-69	0	0%	0	0%
70-74	0	0%	0	0%
75-79	0	0%	2	0%
80-84	1	0%	1	0%
Unknown	334	11%	1	0%
Total	3033	100%	753	100%

Table 2.
Occupant fatality data key statistics (2012 to 2016)

	Average age (years)	Mode	Minimum age (years)	Maximum age (years)
Australia	12.7	14	0	83
New Zealand	16.1	18	0	83

The results comparing the age of vehicles involved in occupant fatalities and the age of vehicles within the fleet are shown separately for each year in Australia and New Zealand in Figures 1 and 2 below.

Australia

The results found that in Australia during 2016, vehicles built in 2012 or later represented the largest portion of registered vehicles at 31%, and were involved in the fewest occupant fatalities at 12%. Vehicles built between 2007 and 2011 represented 27% of registered vehicles and were involved in 13% of occupant fatalities. Vehicles built between 2002 and 2006 represented 22% of registered vehicles and were involved in 21% of occupant fatalities. The oldest group, those built in 2001 or earlier, represented the smallest portion of registered vehicles at 20% and held the largest share of occupant fatalities at 36%.

On average over the five-year period analysed, the newest vehicles aged up to four years (at the time of crash) represented 31% of registered vehicles in Australia and were involved in 12% of occupant fatalities. The oldest age group, those vehicles aged 15 years or older, represented 20% of registered vehicles on average and were involved in 34% of occupant fatalities.

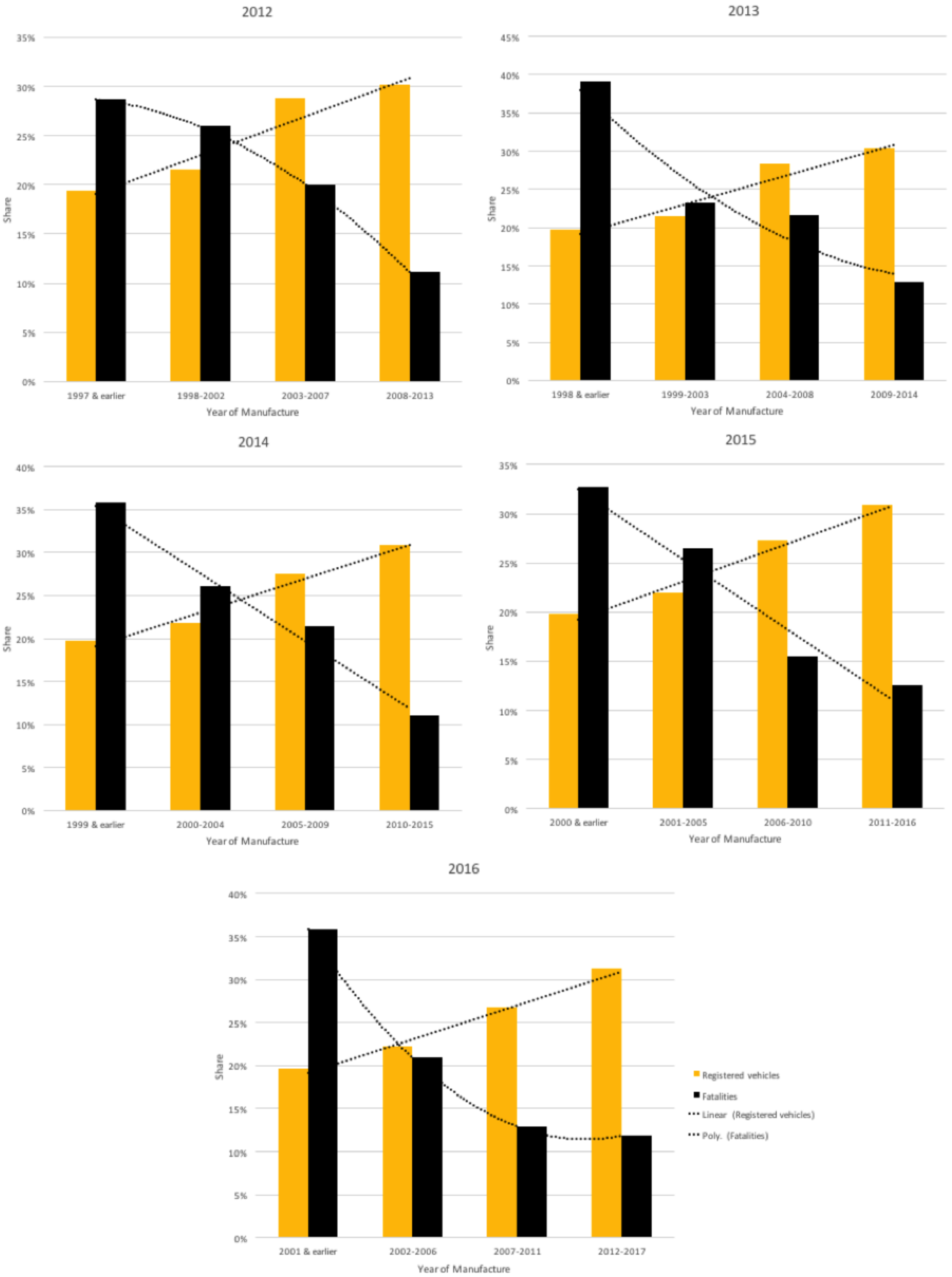
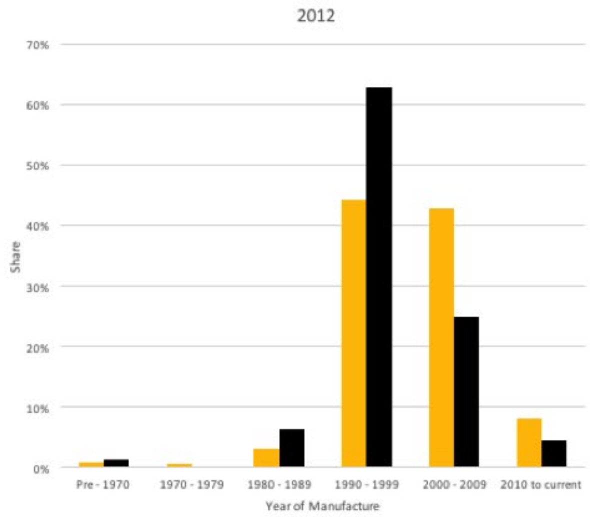


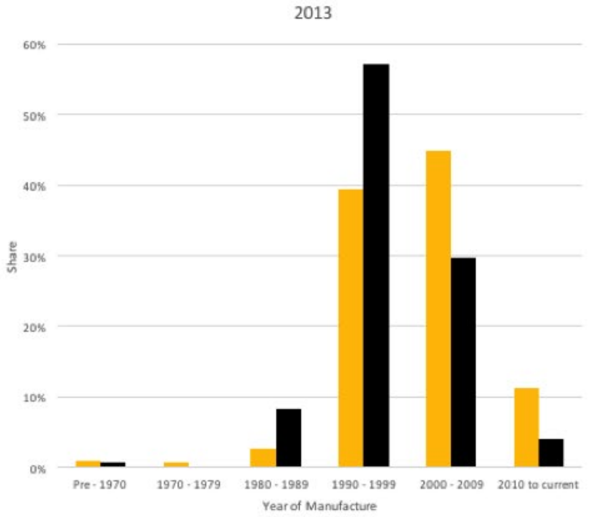
Figure 1 Age of vehicles involved in occupant fatalities vs age of registered vehicles (light passenger vehicles and SUVs) in Australia

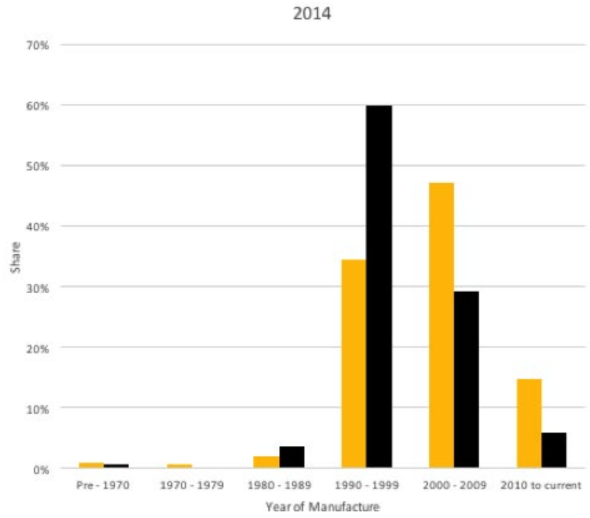
New Zealand

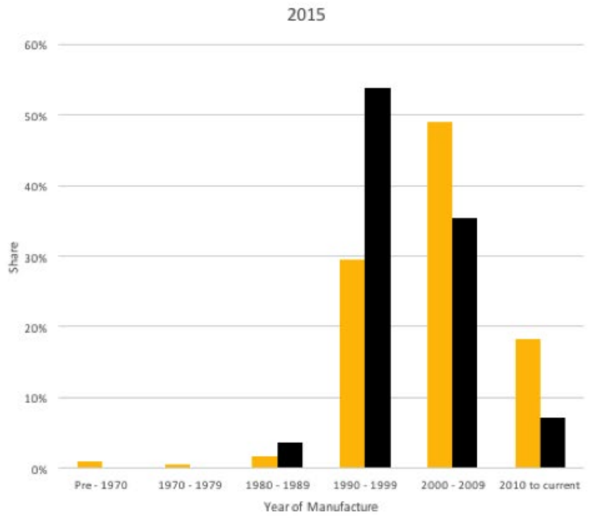
The results found that in New Zealand for 2016, the newest vehicles built in 2010 or later represented 22% of licensed vehicles and were involved in 6% of occupant fatalities. Vehicles built between 2000 and 2009 represented 50% of licensed vehicles and were involved in 44% of occupant fatalities. Vehicles built from 1990 to 1999 represented 25% of licensed vehicles and were involved 45% of fatalities. Vehicles built prior to 1990 collectively represented 3% of licensed vehicles and were involved in 5% of occupant fatalities.

The New Zealand analysis shows relative consistency over the five-year period for vehicles built between 1990 and 2009. On average over the period, vehicles built between 1990 and 1999 represented 35% of licensed vehicles and were involved in 56% of occupant fatalities, while vehicles built between 2000 and 2009 represented 47% of licensed vehicles and were involved in 33% of occupant fatalities.









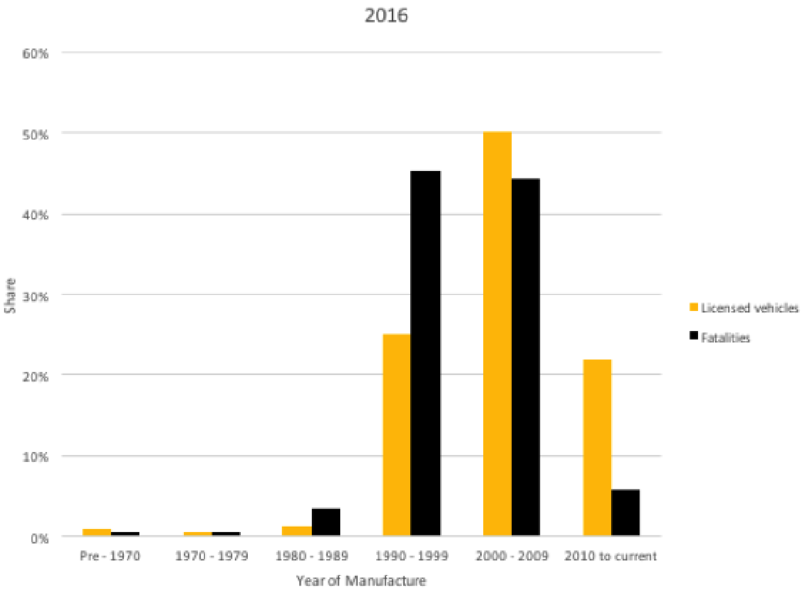


Figure 2. Age of vehicles involved in occupant fatalities vs age of licensed vehicles (light passenger vehicles and SUVs) in New Zealand.

The differing age groupings reported by Australia and New Zealand, due to the differing reporting methods of the respective fleet statistics, make comparisons between the two datasets difficult. However, limited statistical datasets of the New Zealand fleet were available [6] allowing for some comparison to be made between the results. Figure 3 shows the age of vehicles involved in occupant fatalities in New Zealand during 2016 grouped into age groups common with the corresponding Australian results.

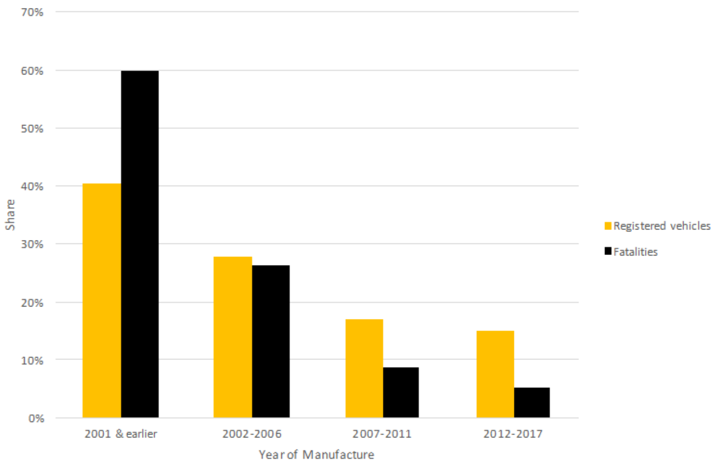


Figure 3. Age of vehicles involved in occupant fatalities vs age of licensed vehicles (passenger vehicles and SUVs) in New Zealand (2016).

Figure 3 shows that in New Zealand during 2016, the oldest vehicles, built in 2001 or earlier, represented 40% of licensed vehicles and were involved in 60% of occupant fatalities. In contrast, the newest vehicles built in 2012 or later represented 15% of licensed vehicles and were involved in 5% of occupant fatalities.

Table 3
Average age of vehicles involved in occupant fatalities

	2012	2013	2014	2015	2016	2012-2016
Australia						
Fatalities	12.2 years	12.8 years	12.5 years	12.9 years	13.1 years	12.7 years
Registered vehicles	9.8 years	9.8 years	9.8 years	9.8 years	9.8 years	9.8 years
New Zealand						
Fatalities	15.7 years	16.4 years	15.6 years	15.9 years	16.8 years	16.1 years
Licensed vehicles	14.0 years	14.2 years	14.2 years	14.3 years	14.4 years	14.2 years

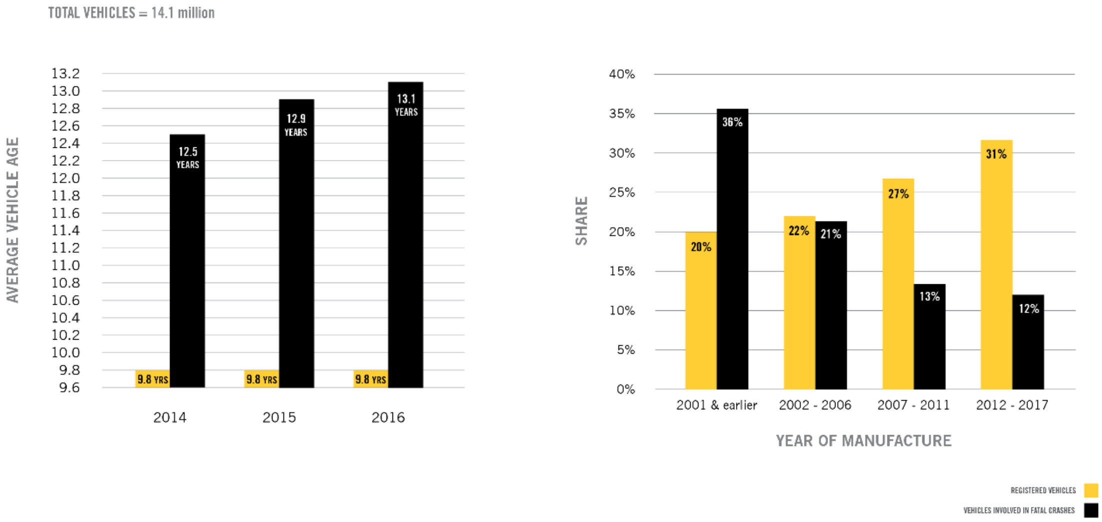


Figure 4. Fatalities vs. Registered Vehicles, Australian Light Vehicle Fleet (passenger cars & SUVs)

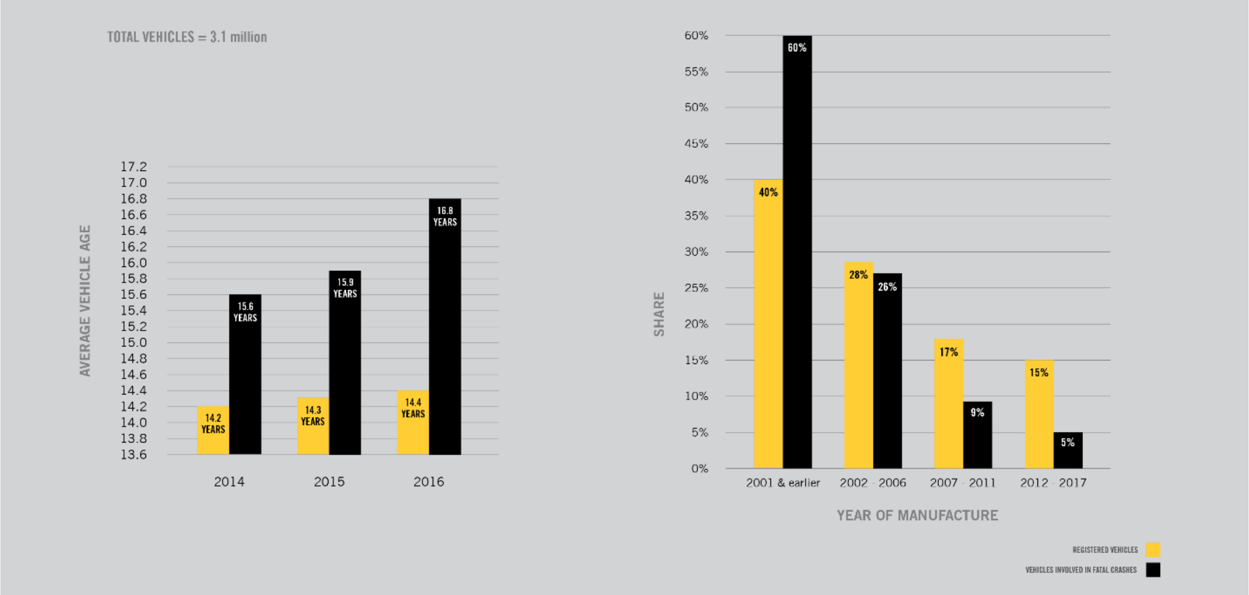


Figure 5. Fatalities vs. Registered Vehicles, Australian Light Vehicle Fleet (passenger cars & SUVs)

Analysis Discussion

The results of the analysis show that older vehicles were consistently over-represented in occupant fatalities in both Australia and New Zealand over the period 2012 to 2016. Australian Motor Vehicle Census data consistently shows a relatively linear relationship between vehicle age and the share of the registered vehicle fleet over the five-year period, with fleet share decreasing with vehicle age. In contrast, the results suggest the relationship between vehicle age and involvement in occupant fatalities is the reverse, with crash involvement increasing with vehicle age. This relationship however is limited, as shown in Table 1, where vehicles aged 25 years and older were involved in much fewer occupant fatality crashes.

Over the five-year period, the Australian results consistently show that the oldest group of vehicles reported in the Motor Vehicle Census data represented the smallest portion of registered vehicles, yet were involved in the most occupant fatalities. Contrast to this, the newest vehicles represented the largest portion of registered vehicles and were involved in the smallest portion of occupant fatalities.

The New Zealand results comparing the age distribution of vehicles involved in occupant fatalities and licensed vehicles in the fleet presents differently due to the vehicle age groups provided in the source fleet statistics datasets. Vehicles built between 1990 and 1999 were consistently over-represented in occupant fatalities while vehicles built between 2000 and 2009 were consistently shown to be involved in less fatalities yet represented more of the licensed fleet. The portion of registered vehicles built in 2010 or later increased over time as expected, however the involvement of those vehicles in occupant fatalities remained relatively constant.

In comparing the results between Australia and New Zealand, Figure 3 suggests a differing relationship between vehicle age and share of the licensed vehicle fleet in New Zealand, with newer vehicles representing less of the fleet than older vehicles. However, the relationship between vehicle age and involvement in occupant fatalities does appear similar, increasing with age.

This observed difference between the Australian and New Zealand distribution of vehicle age amongst the fleet reflects significantly differences in fleet profiles. Notably in New Zealand, used imports represent roughly 50% of the passenger vehicle and SUV fleet [15].

Over the five-year period, the average age of vehicles involved in occupant fatalities was found to be consistently older than the average age of vehicles in the respective fleet for both Australia and New Zealand, supporting the notion that older vehicles are over-represented in occupant fatality crashes.

The average age results shown in Table 3 also suggest a potential trend where the average age of vehicles involved in occupant fatalities is increasing. It is plausible that as newer vehicles become safer, and therefore are involved in fewer serious crashes, the share of serious crashes which older vehicles are involved in may increase. This does, however, imply that overall road fatality numbers will reduce. Further work is needed to establish whether a trend indeed exists or is emerging.

COMMUNITY AWARENESS ACTIVITIES

The findings of the analysis of the Australian and New Zealand registered light vehicle fleet highlighted the need for a redoubling of efforts across all *Safe Systems* pillars, and provided added impetus for ANCAP to enhance community awareness of the importance of newer, safer vehicles beyond the routine publication of ANCAP safety ratings for new market entrants.

New Car Assessment Programs such as ANCAP have the ability to drive improvements in vehicle safety through non-regulatory, consumer information and advocacy activities and this was leveraged through a series of interlinked community awareness activities.

Car-to-Car Advocacy Test

The first of these activities was the conduct of a car-to-car crash test - undertaken to visually communicate the research findings to the general community. The advocacy test was conducted between a 1998 Toyota Corolla hatch and a 2015 Toyota Corolla hatch using similar test parameters as ANCAP's offset deformable barrier (frontal offset) crash test at 64 kilometres per hour with a 40 per cent offset on the driver's side.

The older vehicle sustained catastrophic structural failure with dummy readings showing a high risk of serious head, chest and leg injury to the driver. The 1998 model achieved a score of 0.40 out of 16.00 points which would fall within the parameters for a zero star ANCAP safety rating. In contrast, the 2015 model performed well, scoring 12.93 out of 16.00 points – within five star parameters. Test results and imagery were distributed widely with unprecedented global public interest.

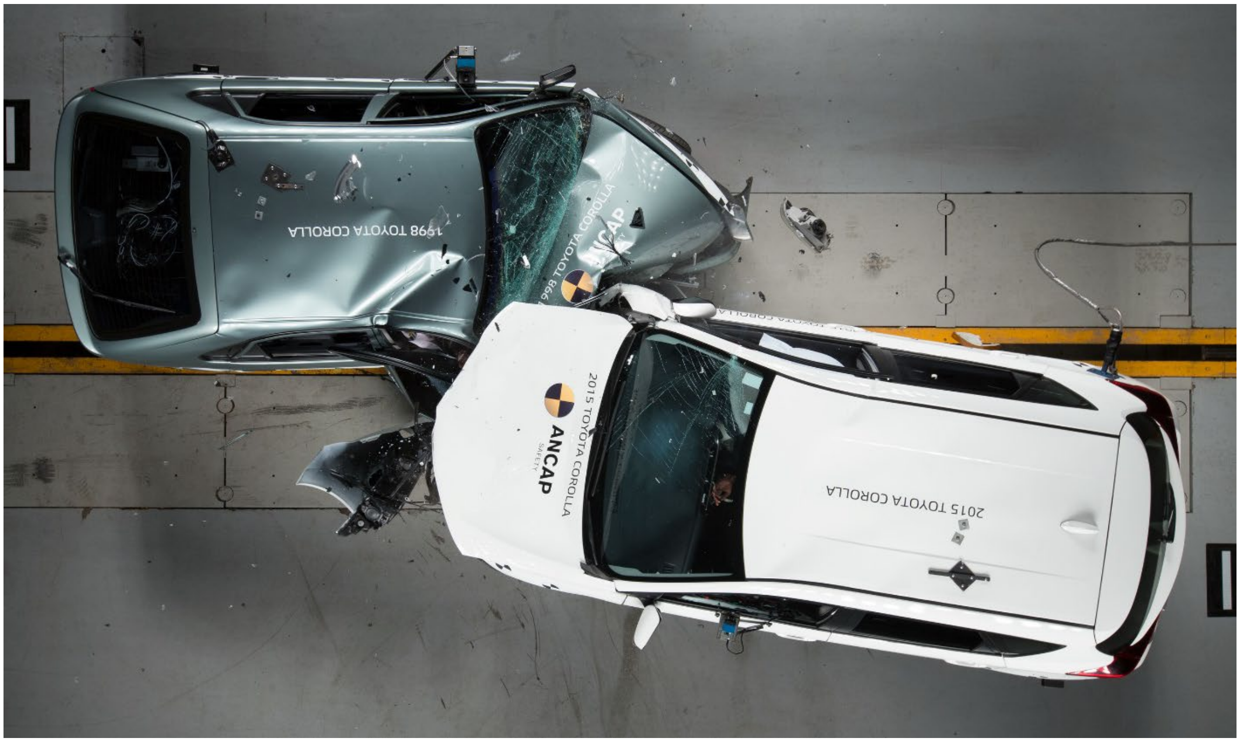


Figure 6. ANCAP car-to-car advocacy test between 1998 Toyota Corolla and 2015 Toyota Corolla (2017).

National Community Awareness Campaign

Drawing upon the public success of the car-to-car test, a national community awareness campaign was derived, titled '*Safer Vehicle Choices Save Lives*'[18]. The primary element of the campaign was the production and national screening of two parallel television commercials (TVC) with the premise to highlight the different crash outcomes between occupants of older vehicles and occupants of more contemporary vehicles. The commercials were produced to evoke consumer awareness and active consideration of vehicle age as a key contributing factor in road fatalities, and the effect safer vehicle choices can have on reducing road trauma.

Vision of the car-to-car advocacy test was incorporated into the commercials with the viewer left to consider the fate, or survivability, of each driver based on the safety performance of the two vehicle models. The call-to-action used in the commercials was, "*Find out who survives*".

This was the first national road safety campaign released in Australia which highlighted the *vehicle* as the determining factor in crash survivability.

Campaign execution

The campaign commenced national rollout from July 2018 in collaboration with all 23 ANCAP member organisations. While nationally-executed, campaign materials were produced for carriage across all Australian states and territories through the use of tailored branding and inclusion of local vehicle registration plates to reinforce jurisdictional relevance to the viewer.

By August 2018, over two thirds of Australia's total population, or 78 per cent of its car driving population, had been exposed to the campaign achieving an audience reach figure of 15.26 million [19] through a moderate investment of AUD$225,000.

Campaign effectiveness

Formal evaluation of the effectiveness of the campaign - including recall, messaging and behavioural impacts - was undertaken half way through the execution of the campaign. 1,041 respondents across all Australian state and territories – regional and metropolitan – were surveyed to explore unprompted and prompted recall and cut-through. In order to provide a nationally representative sample the survey targeted respondents from a mix of genders, age ranges (18-65 years), and driving status (drivers and non-drivers) [20].

The survey revealed a very high level of consumer impact, and attitudinal and behaviour change. As a result of seeing the campaign, respondents were compelled to think, discuss and act. It prompted 29 per cent of respondents to *consider* and 27 per cent to *check* the safety of their current vehicle(s). For one in five (21 per cent), this meant visiting the ANCAP website. This correlated to a 15.2 per cent increase in visitors to the ANCAP website when compared against the same period the year prior. Seventy (70) per cent of respondents stated they would check the ANCAP safety rating before buying their next car.

More serious reflections such as considering purchasing a new car (13 per cent) or actually committing to purchase a safer car (12 per cent) were also reported. One in three (34 per cent) reported feeling compelled to discuss car safety with others. Eighty (80) per cent of respondents stated the campaign message was '*Very / Quite Good*'.

Message recall was also strong with 72 per cent of respondents stating the campaign related to the importance of newer, safer vehicles.

LIMITATIONS

A key limitation to the research findings is that the study does not investigate crash causation and factors contributing to the involvement of vehicles of various ages in fatal crashes. Driver demographics are considered a significant factor contributing to older vehicle involvement in serious crashes with many older vehicles being driven by more at-risk drivers, such as the young and inexperienced, and the elderly and frail [21].

The size of the dataset and statistical significance of the results, particularly New Zealand, also presents a limitation in the reliability of the analysis findings.

CONCLUSIONS

Investigating the involvement of vehicle age in fatal crashes and comparing the age distribution to that of the registered / licensed fleet over the period 2012 to 2016, found that older vehicles aged between 15 and 25 years old were consistently over-represented in road fatalities where the occupant of a passenger vehicle or SUV was fatally injured. Significantly older vehicles aged 30 years or more were not found to be significantly involved in occupant fatality crashes.

The average age of vehicles involved in occupant fatality crashes each year over the analysed period suggests a potential trend towards an increasing over-representation of older vehicles involved in occupant fatalities, which may be influenced by a reduced involvement of newer vehicles in occupant fatalities.

Equal in importance to understanding road safety challenges is to undertake independent testing to prove it, and then activate change through public communication and advocacy. Non-regulatory, consumer-focused communications activities can have a positive impact on consumer behaviour and vehicle choice. The '*Safer Vehicle Choices Save Lives*' campaign, while activated through a modest investment, has achieved strong consumer cut-through and resultant behavioural change.

Active consideration of vehicle safety among the general community can be bolstered through the conversion of scientific testing into compelling and effective consumer-facing materials screened through mainstream and social media. This can be leveraged further by partnering with credible organisations which are relevant and resonate with the viewer. Public advocacy activities such as this can and should be applied globally to assist in reducing the age of registered vehicles and subsequently drive down road trauma.

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TRENDS IN PEDESTRIAN PROTECTION FOR VEHICLES RATED BY AUSTRALASIAN NCAP

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ABSTRACT

Analysis of scores in pedestrian protection tests conducted by ANCAP between 2001 and 2017 indicates that the average score has improved from 7.5 to 25. This has been achieved by steady improvement in the design of relevant vehicle components. Many of these improvements are unlikely to have significant adverse effects on costs or vehicle appearance, provided that good design for pedestrian protection is taken into account early in the design phases for the vehicle.

Based on several real-world crash studies, it is estimated that the improvement of 17.5 points is associated with a 21% reduction in the risk of serious injury for pedestrians.

The improvement was likely driven by NCAP programs in Europe, Australia and Japan, the introduction of GTR9/UN127 in most developed nations (but not Australia) and, more recently, fleet demand for 5-star rated vehicles.

INTRODUCTION

In 2000 the Australasian New Car Assessment Program (ANCAP) commenced rating pedestrian protection using the same protocol as Euro NCAP. This has enabled some Euro NCAP results to be used for ANCAP ratings. Between 2000 and 2017 ANCAP rated more than 600 vehicles, with about half of these ratings based on tests carried out by Euro NCAP. Almost one third of the pedestrian tests were carried out by the Centre for Automotive Safety Research (CASR) in Adelaide, South Australia.

This paper sets out the results of an analysis of the trends with pedestrian protection ratings during the period 2001-2017. An estimate is made of the road trauma savings due to improvements in pedestrian protection.

BACKGROUND

The role of the design of the front of the vehicle in the risk of serious injury to pedestrians has been recognised for many years. Fisher and Hall (1972) looked at the influence of frontal design and speed of impact. Harris (1976) developed early test procedures using the sub-system approach where separate impacts are conducted using headforms and legforms to simulate a collision between pedestrian and vehicle. The European Enhanced Vehicle Safety Committee (EEVC) developed a draft protocol in the late 1980s. This became the basis of the first Euro NCAP protocol for pedestrian protection, which was implemented in 1997 (Lawrence & Hardy 1998).

ANCAP implemented the same pedestrian protection protocol as Euro NCAP in 1999, as part of a package to align with Euro NCAP test and assessment protocols. The first ANCAP results were published in 2000 (Paine & Coxon 2000). Since then CASR has conducted testing for ANCAP and contributed to the development and interpretation of the Euro NCAP protocols.

Test protocol

The test protocol requires three sets of sub-system tests. Impactors used for these tests represent an adult head and a child head striking the bonnet and windscreen areas, an upper legform striking the leading edge of the bonnet and a lower legform striking the bumper fascia. Scores are allocated on the basis of the head injury criterion (HIC) when using the head impactors (maximum 12 points each for the child and adult head impactors respectively), bending moment and forces in the case of the upper legform (maximum 6 points) and for the lower leg impactor shear displacement, knee bend angle and tibia acceleration were measured giving a maximum 6 points.

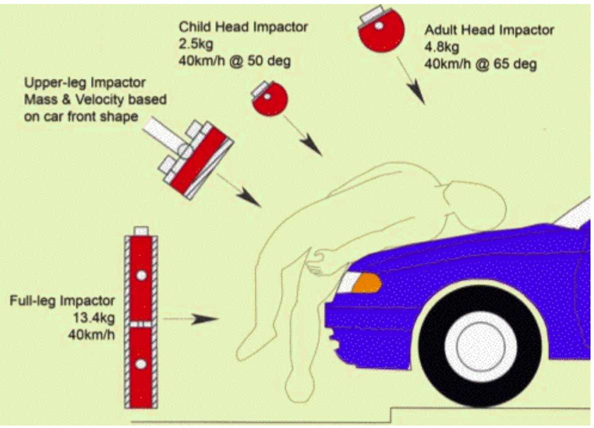

Figure 1. Sub-system tests for pedestrian protection (circa 2008)

An overall score is derived by summing the subsystem scores. Over the period of analysis the maximum available overall score has remained at 36. Between 2000 and 2010 the results were presented as star ratings and as a descriptive rating from 2011:

Table 1 ANCAP Pedestrian Protection Ratings

Score	2000-2010	2011+
27.5 or more	4 stars	Good
18.5 to 27.49	3 stars	Acceptable
9.5 to 18.49	2 stars	Marginal
0.5 to 9.49	1 Star	Poor
Less than 0.5	Zero stars	Poor

There were minor changes to the protocol in 2002 (discussed in Ponte et al., 2004) and significant changes in 2010. The 2010 change generally resulted in lower scores (Ponte et al., 2013).

In 2012 ANCAP introduced the "grid method" where the vehicle manufacturer submits detailed head impact test results for every 100x100 mm grid location and the ANCAP laboratory conducts verification tests on a sample of grid locations. An adjustment is made to the final manufacturer expected score if there is a discrepancy between the submitted and verification test results. These changes also influenced the pedestrian protection scores, but to a lesser extent than the change in 2010.

In 2015 ANCAP replaced the "TRL" lower legform with the "FlexPLI" legform and also made significant changes to the location, energies and performance criteria for the upper leg impactor.

No adjustment for these effects has been made in the following analysis but, generally, the observed improvements will be conservative (vehicles rated to the newer protocols will have slightly better pedestrian protection than the scores suggest).

Other influences on vehicle design

In 2009 Global Technical Regulation 9 (GTR9/UN Regulation 127) "Pedestrian Safety" was published by the United Nations. In 2011 the Australian Department of Infrastructure and Transport issued a Regulation Impact Statement (RIS) recommending that the GTR be implemented as an Australian Design Rule (Department of Infrastructure and Transport, 2011). However, the RIS was withdrawn and the initiative did not go ahead (King, 2011). The latest WHO report on the Global Status of Road Safety notes that "Australia has signed the UN127 for Pedestrian Protection as a Contracting Party but is not enforcing it." (WHO 2018).

Although Australia has not implemented GTR9/R127 it is likely that most cars marketed in Australia have been designed to meet the requirements since they are usually also sold in Europe or Japan. Exceptions are where the extra features such as a pop-up bonnet are standard in Europe/Japan but not in Australia or where additional (e.g. aftermarket bullbars) structures are fitted to the front of the vehicle .

In 2012, under its new Road Map, ANCAP set a minimum pedestrian protection performance threshold as part of an assessed vehicle's overall star rating, (ANCAP 2011). This provided much stronger incentive for manufacturers to do well in the pedestrian impact tests. The Road Map requirements became progressively more stringent between 2012 and 2017. For example, to earn an overall rating of 5 stars in 2012 a vehicle needed at least a “marginal” pedestrian protection rating (minimum of 9.5 points). This increased to a requirement of an “acceptable” rating (minimum 18.5 points) in 2014.

The 2011 ANCAP Road Map set lower pedestrian safety performance requirements for high-seat vehicles (some SUVs, 4WDs, utilities and vans) in recognition of industry claims about the challenges faced in designing these vehicles to perform well in pedestrian protection tests. For example, a pedestrian protection rating of “acceptable” (18.5 or more) was not required for an overall 5 star rating of high-seat vehicles until 2017. However, soon after ANCAP published its 2011 Road Map, Euro NCAP awarded the Australian-designed Ford Ranger pickup the highest score for pedestrian protection of any vehicle tested (at the time), bringing into question the claims about high-seat vehicles.

In 2012 BHP introduced an NCAP 5-star requirement for company light vehicle purchases and for contractors using BHP worksites (Jenkins 2012). Because Euro NCAP and ANCAP included pedestrian protection in the assessment this likely resulted in improved pedestrian protection for vehicles typically purchased by mining companies.

Figure 2. Ford Ranger - a high-seat vehicle that provides good pedestrian protection

SOURCES OF DATA

A database of ANCAP safety ratings from 2000, maintained by one of the authors, was analysed to determine trends in pedestrian protection scores. Only overall scores were analysed.

The trends in pedestrian protection scores were compared with a recent analysis of trends in pedestrian injury in road crashes in Australia and New Zealand (Keall et al., 2018).

RESULTS

Figure 3 illustrates the results of the analysis. A linear trend line for all vehicle types indicates that the average pedestrian protection score improved from 7.5 in 2001/2 to 25 in 2017, a threefold improvement.

Note that the values are based on the number of ANCAP ratings for each vehicle type and the year in which the tested model was released. The method does not account for annual sales. Vehicle types with small sample sizes are not shown in the chart but are included in the overall values ("All"). Appendix B has a table with all data.

RISK OF INJURY

Paine and Coxon (2000) describe Transport Research Laboratory estimates that 8% of all pedestrian fatalities and 21% of all pedestrian serious injuries in the Europe could be prevented through improved vehicle design. The research was associated with Euro NCAP introducing pedestrian protection tests in 1997 (Lawrence 1998).

There have been several studies looking for a correlation between NCAP pedestrian protection scores/ratings and real-world injury to pedestrians. For the purpose of comparison, in the following analysis we translate the estimated injury savings to a percentage reduction for a 10-point improvement in ANCAP/Euro NCAP pedestrian protection score.

Lawrence and others (2006) estimated that introducing the GTR for pedestrian protection in Europe would result in a 4% reduction in fatalities and a 12% reduction in serious injuries. It should be noted that vehicles which score well in NCAP testing are likely to pose a lower risk of pedestrian injury than vehicles which just meet the minimum

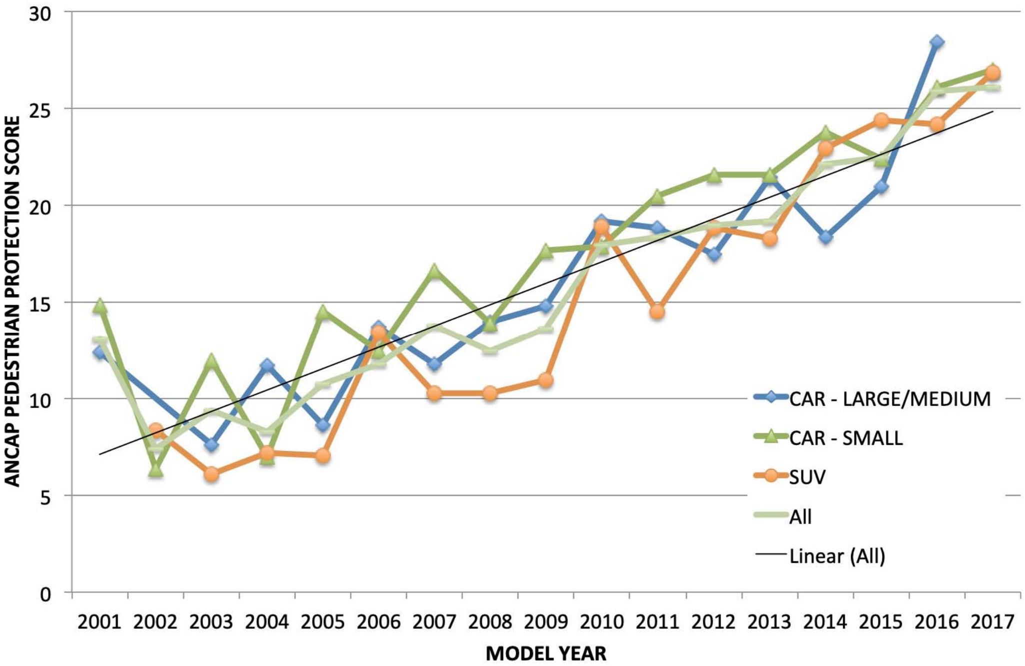

Figure 3. Average ANCAP Pedestrian Protection Scores

requirements of the GTR and so benefits of a high NCAP score will be greater. Based on this, it is estimated that the benefit from a 10-point improvement in NCAP score is at least a 12% reduction in serious injuries.

The Australian RIS that attempted to introduce GTR9 in 2011 used Lawrence's estimates in the benefit-cost analysis (Department of Infrastructure and Transport, 2011).

Strandroth et al., (2011) analysed 609 Swedish crashes where a Euro NCAP-rated vehicle collided with a pedestrian. They grouped the vehicles into 1 and 2 star pedestrian ratings (there were insufficient cases of 3 stars or better). The average score was 6.24 for 1-star vehicles and 13.84 for 2-star vehicles. It was found that injury severity was lower for 2-star cars compared to 1-star cars, with the relative difference in serious injuries (AIS2+) being 17% lower with 2-star cars and severe injuries (AIS3+) were 28% lower, compared to 1-star cars.

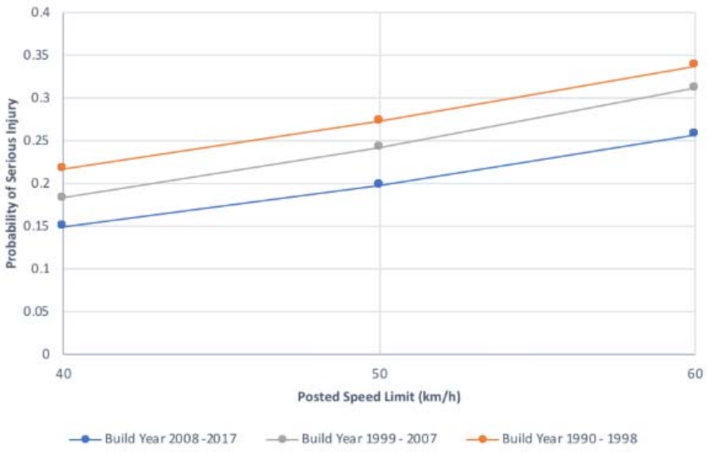

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Figure 4. Probability of serious/fatal injury for pedestrians struck by a car in South Australia (1990-2016)

This is equivalent to a 22% reduction in serious injury risk for a 10-point improvement in NCAP score.

Pastor (2013) analysed the German National Accident Records and, from 7,576 relevant records, found that the risk of a fatality is reduced by 35% for a vehicle scoring 22 for pedestrian protection, compared with a vehicle scoring 5. The risk of serious injury was reduced by 16%. This is equivalent to a 9.4% reduction in serious injury risk for a 10-point improvement in score.

Keall and others (2018) analysed data on police-reported road crashes in Australia and New Zealand and calculated the risk of serious injury to pedestrians by vehicle type and year of manufacture. Based on that analysis the average risk for vehicles manufactured between 1997 and 2001 was 39.4% compared with 33.6% for vehicles manufactured between 2007 and 2012. This is a 15% reduction in risk.

Over the period 2001 to 2012 the average ANCAP pedestrian protection scores improved from 7.5 to 17. The Keall study did not look specifically at ANCAP pedestrian scores and there are numerous confounding factors but over the period when ANCAP scores improved by 10 point there was an observed 15% reduction in the risk of serious injury to pedestrians.

One of the present authors recently examined South Australian pedestrian crash data from 1990 to 2016. A total of 1,118 serious injury crashes were analysed using a logistic regression model to predict the probability of a fatality or hospital admission. Figure 4 presents the key results of the analysis for posted speed limits of 40, 50 and 60 km/h. The probability of serious injury for vehicles built between 2008 and 2016 was around 19% less than those built between 1999 and 2007. The average ANCAP pedestrian scores for these two build date ranges were 11 and 19 respectively.

Figure 5 shows the derived values for the five studies. Overall it is estimated that a 10 point improvement in NCAP score is associated with a 16% reduction in serious injuries to pedestrians.

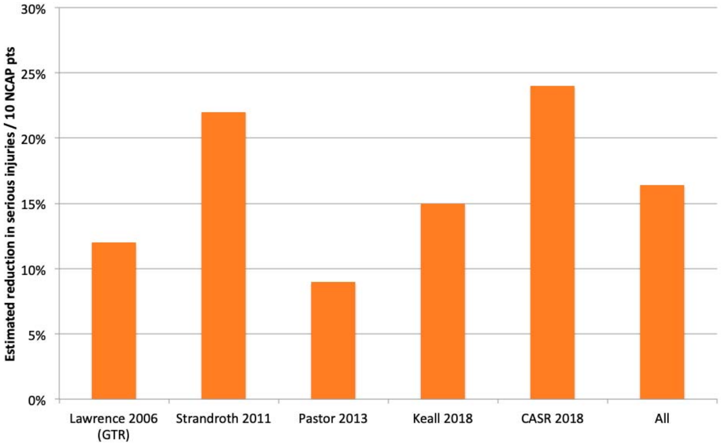

Figure 5. Derived reduction in serious injuries to pedestrians due to a 10 point improvement in NCAP score

Therefore, assuming a linear relationship, the observed 17.5 point improvement in average ANCAP pedestrian scores between 2001 and 2017 equates to a 29% reduction in serious injuries over this period.

IMPROVEMENTS TO VEHICLE DESIGN

Several of the papers referred to above contain observations and information about vehicle design to improve pedestrian protection.

Lawrence (1998) notes that that relatively simple changes to detail in the early design stages of a new model can lead to major improvements in pedestrian protection. Suggested improvements include front bumper fascia re-design (deeper profile, with localised compliance and energy absorption), headlamps (plastic better than glass), bonnet leading edge (locate bonnet latch further rearwards, relocate transverse stiffeners) and bonnet/fender tops (design for crush, increase under-bonnet clearances).

The Australian RIS (Department of Infrastructure and Transport, 2011) quotes the head of a vehicle insurance research organisation that is an ANCAP stakeholder and also conducts evaluations of the cost of repairs in low speed collisions: "...this proves that manufacturers can design vehicles that can perform well in both pedestrian safety and vehicle protection".

The RIS also referred to UK research (Lawrence, 2006) that estimated the cost of design changes to meet the GTR requirements ranged from 27 Euro for a small family car to 47 Euro for a large SUV. However, it was noted that executive cars and sports cars might need relatively expensive active safety such as pop-up bonnets (subsequent Euro NCAP ratings effectively show that this is not essential for meeting the GTR).

Two of our authors have conducted pedestrian protection test for ANCAP over many years. They have observed a change in attitude of vehicle manufacturers towards these tests. In particular, many manufacturers have appointed engineers who specialise in design for pedestrian protection and these engineers have frequently attended the ANCAP testing.

Most of the improvements in head protection are the result of optimising the deformation characteristics of the vehicle's hood, to help 'cushion' the head in a pedestrian head impact. Additionally, allowing adequate space between the under-surface of the optimised vehicle hood and any hard structures underneath it has also been undertaken by most manufacturers to ensure the protective design of the hood is not undone by a rigid structure within the deformations zone (see Hutchinson et al., 2011). This has been observed during testing, as manufacturers are genuinely considering the height and placement of rigid structures such as suspension towers, batteries and engine intakes so deformation space is provided during an impact. Traditionally rigid hood support areas have also been addressed to improve head protection. Examples include moving the top of the firewall lower and rearward and placing a collapsible plastic plenum to create the seal between the rear of the hood and the firewall (a traditionally stiff hood support area). Similarly, the structures of the sidewall supports of the engine bay have been lowered, and collapsible brackets have been used to position wheel guard panels so head impacts in these areas are also less severe.

For vehicles with restrictions on available under bonnet space, active safety systems such as deployable or "pop-up" hoods are being used to create space and give clearance between rigid structures beneath the hood, during a head impact.

Improvements for lower leg protection include the addition of energy absorbers (foam or crush cans) and lower stiffening rails to keep a pedestrian's leg from bending under the front of the vehicle.

Improvements to the upper leg area have involved moving the radiator support and the bonnet latch rearward and creating space between the latch and outer bonnet surface. Headlights with plastic lenses (instead of glass) with breakaway mounting tabs also improve pedestrian protection.

Appendix A contains examples of the changes observed by CASR personnel.

DISCUSSION

The importance of good vehicle design in preventing serious and fatal injuries to pedestrians was recognised in the 1970s at a time when regulations were introducing substantial improvements to vehicle occupant protection (e.g. seat belts). However, the development of suitable test methods for assessing pedestrian protection did not make good progress until the late 1980s, mainly through the work of EEVC.

Euro NCAP introduced pedestrian protection ratings in 1997 as part of its new vehicle safety program. NCAPs in Australia and Japan introduced pedestrian protection ratings a few years later. These consumer programs found that most vehicles of the day had woeful designs for pedestrian protection, although a few vehicles demonstrated that good design was possible without compromising style and functionality.

The first international regulation for pedestrian protection (GTR9/UN127) was published in 2009. Around this time Euro NCAP began to require reasonable performance in pedestrian tests as part of its overall rating. These two developments likely focussed vehicle manufacturer attention on improving vehicle designs for pedestrian protection.

In 2011, the Australian government halted the process to implement GTR9/UN127 but it is likely that the Australian vehicle fleet still improved in terms of pedestrian safety, due to overseas developments (since most vehicles sold in Australia are built overseas). This would have been boosted by ANCAP adding pedestrian protection to its overall rating requirements from 2012.

ANCAP ratings show that there has been a steady improvement in pedestrian protection scores between 2011 (18) and 2017 (25). Noting that just passing the GTR is equivalent to an ANCAP score of 18 (Anderson et al., 2008), it is considered that most of the improvement can be attributed to NCAP programs in Europe, Japan and Australia.

In summary we agree with this statement: "In the absence of any pedestrian regulation in Australia, the incorporation of the pedestrian assessment as part of the ANCAP star rating is by far the most important mechanism for compelling manufacturers to think ‘outside the car’ and incorporate pedestrian safety in vehicle design." (Ponte et al., 2013)

LIMITATIONS

It took several years for ANCAP to assign ratings to a large proportion of all models for sale in Australia and New Zealand. During the period 2001 to 2004 the ratings were dominated by models tested by Euro NCAP. These tended to be luxury models in Australia and this may have influenced the trends in early years.

Protocol changes described above will have influenced the scores and this has not been taken into account in the analysis of results in this paper.

ANCAP pedestrian protection ratings have not been the sole influence on pedestrian injury during the study period. Europe implemented GTR 9 in 2009 and many cars entering the Australian market since then are likely to have been designed to that regulation.

In 2003, most Australian states reduced residential speed limits from 60k/h to 50km/h. This had a substantial effect on pedestrian fatalities on these roads (Woolley, 2005). Additionally, there was also a reduction in pedestrian casualty crashes (and mean speeds on various roads) as a result of the speed limit changes (Kloeden et al., 2007). The speed limit changes perhaps brought many more car/pedestrian collisions into the 40 km/h impact range, where improved frontal design can be more effective.

Some variation between real-world and laboratory results is understandable because the ANCAP tests simulate a collision at 40km/h and collisions between cars and pedestrians occur over a much wider range of speeds. Design improvements that mitigate a 40km/h collision are unlikely to be as effective at 50km/h or higher speeds (Strandroth et al., 2011). In this regard, the data used for the CASR analysis was confined to posted speed limits from 40 to 60km/h.

The assumption of a linear relationship between NCAP score and risk of serious injury has not be verified but it is considered that over a small range of scores this assumption is reasonable.

CONCLUSIONS

ANCAP pedestrian protection testing between 2001 and 2017 indicates a steady improvement in vehicle design over this period, with the average score improving from 7.5 to 25. Based on several real-world crash studies, it is estimated that this improvement is associated with a 29% reduction in the risk of serious injury for pedestrians.

The improvement was likely driven by NCAP programs in Europe. Japan and Australia, the introduction of GTR9/UN127 in most developed nations (but not Australia) and, more recently, fleet demand for 5-star rated vehicles.

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APPENDIX A - EXAMPLES OF IMPROVEMENTS TO VEHICLE DESIGN (CASR)

Under-bonnet components

Mid-1980s: Stiff firewall and sides of engine bay supporting edge of bonnet. Minimal clearance between suspension tower/air cleaner and bonnet.

Early 2000s: Stiff firewall and sides of engine bay supporting edge of bonnet. Minimal clearance between suspension tower/engine cover and bonnet.

Recent: Firewall and sides of engine bay lowered with bonnet supported by collapsible elements. Suitable clearance is provided between suspension tower/other under bonnet structures and bonnet.

Top edge of fender

Traditional design: Wheel guard supported directly by stiff structure.

Recent design: Wheel guard supported by collapsible element.

Bumper design

Lower support in position to keep leg from bending under car and energy absorbing foam to protect the knee.

Leading edge of bonnet

Bonnet latch moved rearwards and radiator support moved rearward and lowered (recent model)

APPENDIX B - DATA

The following table includes the data presented in Figure 3.

Average ANCAP score for pedestrian protection [number of rated models]

YEAR MODEL RELEASED	CAR LARGE /MEDIUM	CAR SMALL /LIGHT	SUV	ALL
2001	12.4 [7]	14.9 [6]	-	13.1 [15]
2002	-	6.3 [3]	8.4 [9]	7.4 [13]
2003	7.6 [8]	12 [8]	6.1 [7]	9.4 [29]
2004	11.7 [8]	7 [8]	7.2 [4]	8.3 [25]
2005	8.6 [6]	14.5 [13]	7 [4]	10.8 [27]
2006	13.7 [11]	12.5 [6]	13.4 [11]	11.8 [38]
2007	11.8 [7]	16.6 [17]	10.3 [7]	13.8 [39]
2008	13.9 [10]	13.9 [23]	10.2 [7]	12.4 [47]
2009	14.8 [8]	17.7 [18]	10.9 [7]	13.7 [39]
2010	19.2 [5]	17.9 [18]	18.9 [8]	17.9 [33]
2011	18.8 [9]	20.5 [16]	14.5 [9]	18.4 [42]
2012	17.4 [13]	21.5 [10]	18.8 [11]	19 [43]
2013	21.4 [15]	21.6 [12]	18.3 [14]	19.2 [50]
2014	18.4 [3]	23.8 [11]	22.9 [6]	22.1 [30]
2015	20.9 [9]	22.4 [4]	24.4 [18]	22.5 [47]
2016	28.4 [6]	26.1 [13]	24.2 [9]	25.9 [29]
2017	-	27 [3]	26.9 [6]	26.1 [11]

Notes

"ALL" include other types of vehicles with small sample sizes

2001 data were mostly Euro NCAP ratings of "prestige" vehicles, as sold in Australia