A STUDY ON TOUGHENED GLASS USED FOR VEHICLES AND ITS TESTING METHODS

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ABSTRACT

Toughened glass for vehicles is used for most window glass, except for windshield glass, and in particular is also generally used for sunroofs installed on the roofs of vehicles. Toughened glass is known to have external impact resistance that is about four times stronger than original glass.
We would like to verify that ceramic-printed toughened glass does not meet of GTR(Global Technical Regulations) No. 6 and its strength is lower than original glass through tests.
The tests were conducted with the test piece of original glass, toughened glass, and ceramic-printed toughened glass from five glass manufacturers. In Test 1, a 227g steel ball was dropped from a height of 2 meters, and damage was checked according to the test method of GTR No. 6, and in Test 2, a steel ball was freely dropped from different heights and limited damage height was determined.
In the result of Test 1 according to the test method of GTR No. 6, while all five test pieces of toughened glass were not damaged, all the ceramic-printed toughened glass from the five manufacturers were damaged.
In the result of Test 2, none of the five test pieces of toughened glass were damaged by a 10m ball drop, the original glasses were damaged by an average of 3m ball drop, and the ceramic-printed toughened glasses were damaged by an average of 1.4m ball drop.
As the results of the tests show, ceramic-printed toughened glass does not have the features of toughened glass due to its very low strength.
Therefore, we would like to contribute to the safety of consumers by considering the GTR No.6, and by revising the toughened glass test method.

1. INTRODUCTION

Vehicle manufacturers have broadened the ceramic-printed area of toughened glass to improve the external design of vehicles and the attachment of glass to the vehicle body.
The panoramic sunroofs of vehicles are mainly made of toughened glass, and the ceramic-printed area accounts for 30~70%.
According to the details of reports from a vehicle defect reporting center of the Republic of Korea, the defect reports related to panoramic sunroof damage have been increasing in recent years. Therefore, we believe that as the ceramic-printed area has been broadened, the damage of toughened glass that is vulnerable to external impacts have also been increasing, and so have the complaints of consumers.
Hence, we would like to verify the vulnerability of ceramic-printed toughened glass through the test and consider the test method of GTR No. 6.

2. TYPE AND DEFINITION FOR VEHICLE GLASS

a. **Laminated Glass:** Means glazing consisting of two of more layers of glass held together by one or more inter-layers of plastic material.

b. **Toughened glass:** Means glazing consisting of a single layer of glass which has been subjected to special treatment to increase its mechanical strength and to condition its fragmentation after shattering.

c. **Double Glazing:** Double-glazed unit means an assembly of two panes permanently assembled in manufacture and separated by a gap.

d. **Glass-plastic Combination Glass:** Glass-plastic means glazing consisting of any glazing material which comprises one layer of glass and one or more layers of plastic in which a plastic surface of the product faces the inner side.

e. **Original Glass:** This is the glass pane before the process to make safe glass for vehicle.

f. **Ceramic-printed Toughened Glass:** This is the toughened glass which has been toughened after ceramic printing.

3. BALL DROP IMPACT STRENGTH TEST FOR GLASSES

a. Test Purpose

The purpose is to investigate what result comes out when ceramic-printed toughened glass is tested for GTR No. 6 and to compare the impact strength of ceramic-printed toughened glass and original glass.

b. 227 g Ball Drop Test

- **<u>Test equipment</u>**

  - Steel ball: Hardened-steel ball with a mass of 227 g ± 2 g and a diameter of approximately 38 ㎜.
  - Support for ball tests: Supporting fixture, such as that shown in Figure 1, composed of steel frames, with machined borders 15 mm wide, fitting one over the other and faced with rubber gaskets 3 mm thick and 15 mm wide and of hardness 50 ±10 International Rubber Hardness Degree (IRHD).
    The lower frame rests on a steel box 150 mm high. The test piece is held in place by the upper frame, the mass of which is 3 kg. The supporting frame is welded onto a sheet of steel 12 mm thick resting on the floor with an interposed sheet of rubber 3 mm thick and of hardness 50 ± 10 IRHD.
    Figure 1 shows the supporting fixture used for the test and Figure 2 shows the whole device for the ball drop test.

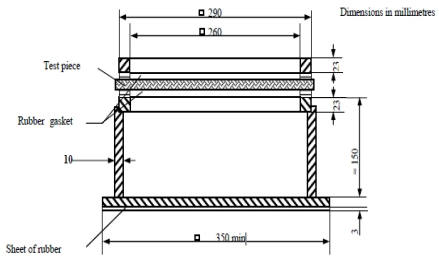

Figure 1. Drawing of Supporter

Figure 2. The test equipment for the ball drop test

- **<u>Test piece</u>**

  - The test piece is manufactured flat, with a size of 300 X 300 ㎜.
  - The thickness of the test piece, which is used for panoramic sunroofs, is 4 ㎜ ± 0.2 ㎜.
  - Type of test piece: Three type of toughened glass, ceramic-printed toughened glass, and original glass from five manufactures. The test piece are marked A, B, C, D, and E.

- **Test 1**

  - Test method: Test according to GTR No. 6
  - Procedure
    ① When a 227 g ball drop test is conducted at a height of 2.0 m ± $^{5}_{0}$ ㎜, the test piece shall not break.
    ② Six test pieces shall be tested and at least five shall meet the requirements.
  - Result of Test 1

Table 1. Result of Test 1(Number of Pass/Number of Tests)

Type of Glass	A	B	C	D	E
Original Glass	Pass(6/6)	Fail(4/6)	Pass(6/6)	Pass(6/6)	Pass(6/6)
Toughened Glass	Pass(6/6)	Pass(6/6)	Pass(6/6)	Pass(6/6)	Pass(6/6)
Ceramic-printed Toughened Glass	Fail(0/6)	Fail(0/6)	Fail(0/6)	Fail(0/6)	Fail(1/6)

As shown in Table 1, the original glass met of GTR No. 6 except for test piece B, and all test pieces of toughened glass met the regulation. However, none of the test pieces of ceramic-printed toughened glass met GTR No. 6.

- **Test 2**

  - Test method: A 227 g ball is dropped every 20 ㎝ from a higher position starting at 1 m till the test piece is broken. When the test piece is broken, the same test piece is tested at the same height.
  - Procedure: When two sheets are damaged at the same height in a row, the height at which test pieces broken shall be taken.
  - Result of Test 2.

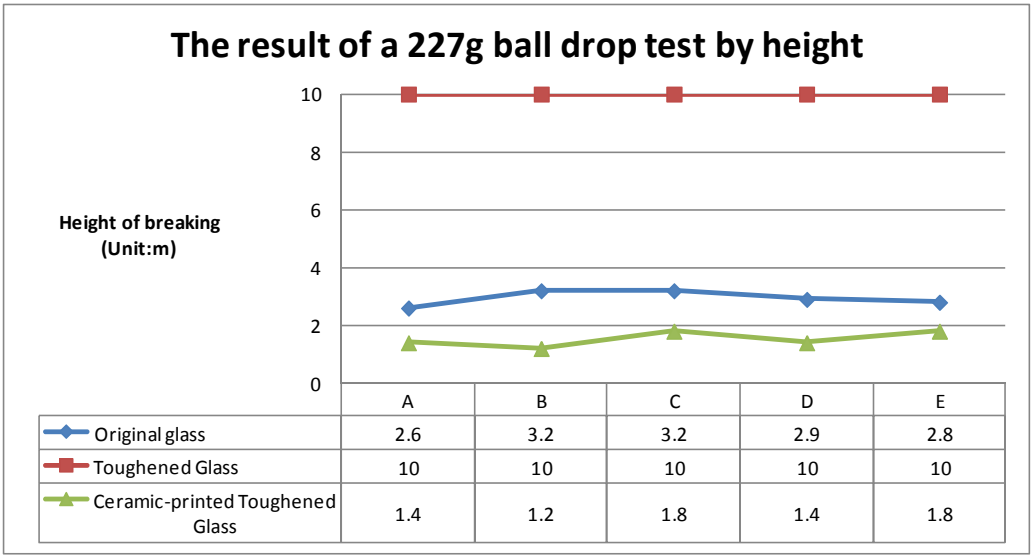

Figure 3. Result of Test 2

As shown in Figure 3, original glass was damaged at an average ball drop height of 3 m. while toughened glass was not damaged at a ball drop height of 10 m. However, ceramic-printed toughened glass was damaged at average height of 1.4 m. Also, the damage height of ceramic-printed toughened glass is lower than the damage height of original glass, showing vulnerability to external impact strength.
Ceramic-printed toughened glass does not meet the feature of toughened glass defined in GTR No. 6 in terms of strength.

4. VULNERABILITY OF CERAMIC-PRINTED TOUGHENED GLASS

a. Toughened Glass Manufacturing Process

The manufacturing process of toughened glass is divided into a pre-treatment process and a toughening process. During the pretreatment process, original glass is cut and ceramic is printed and dried. And during the toughening process, pretreated glass is put into a heating furnace and heated at 600~700℃. And then curvature is given to the glass and it is toughened through a cooling technique (rapid cooling, etc.). Figure 4 shows the manufacturing process of toughened glass by phase.

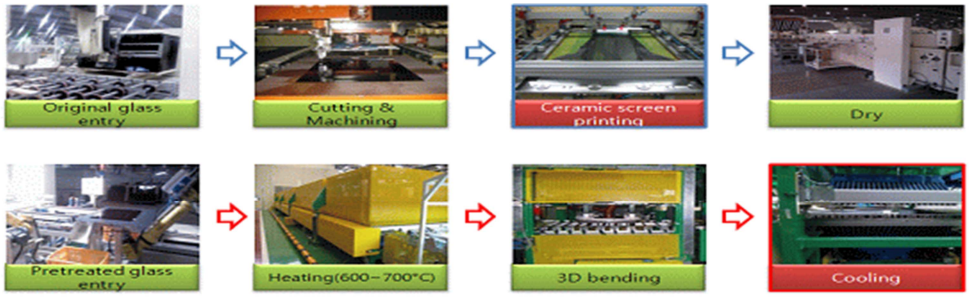

Figure 4. Manufacturing process of toughened glass

b. Stress Distribution of Toughened Glass

In toughened glass finished with a toughening treatment, both outside surfaces are very stable due to compression stress, while the inside is very unstable due to tension stress. Figure 5 shows the stress distribution of general toughened glass.

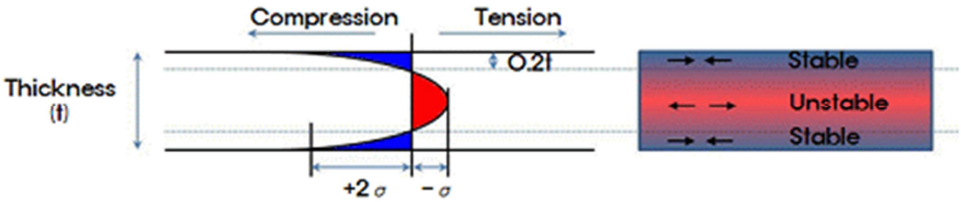

Figure 5. Stress distribution map of cross section of toughened glass

c. Ceramic Printing of Toughened Glass

During the pretreatment process, enamel paint, which is composed of frit, pigment, and medium, is printed on original glass and dried. The glass is then fused with high heat in a furnace at a high temperature. Figure 6 shows the ceramic printing and fusing process of toughened glass.
The reason for ceramic printing is the necessity of having a rough ceramic surface to maintain strong adhesive strength when glass is attached to a vehicle body. The other reasons are the concealment of interior materials and blocking of UV rays.

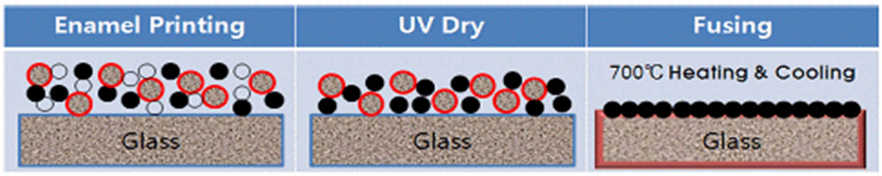

Figure 6. Ceramic melting process of toughened glass

※ Enamal materials: Frit, Pigment(Ceramic), Medium

d. Reason why Ceramic-printed Toughened Glass is Vulnerable

Ceramic fusion of toughened glass makes the glass surface very unstable because it hampers the formation of compression stress on the surface. Figure 7 shows the stress distribution of ceramic-printed toughened glass. The ceramic-printed layer hampers the toughening of glass on the outside surface and marks unstable tension stress work.
Therefore, it can be damaged by a small impact more easily than original glass.

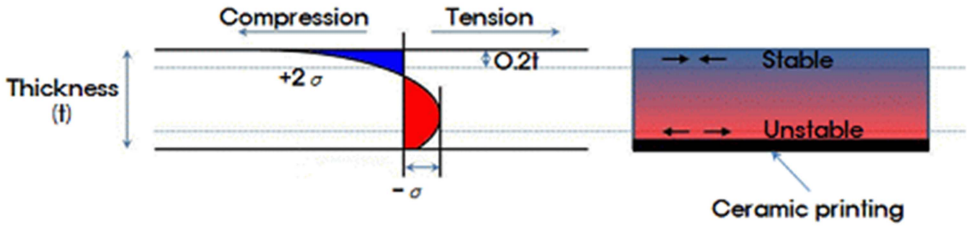

Figure 7. Stress distribution of ceramic-printed toughened glass

e. Case of Ceramic-printed Toughened Glass

Ceramic-printed toughened glass is used for most vehicles. As shown in Figure 8, it is used for sunroofs, side window glass, and rear window glass.

Panoramic sunroof	Side window glass of van	Rear window glass of sedan

Figure 8. Use case of ceramic-printed toughened glass

f. Damage Cases of Ceramic-printed Toughened Glass

Figure 9 shows cases of damage to ceramic-printed toughened glass by external impacts. In all cases, the ceramic-printed area is damaged.

Figure 9. Damage case of ceramic-printed toughened glass

5. CONSIDERATION OF SAFETY REGULATION FOR TOUGHENED GLASS FOR VEHICLES

a. The Global Technical Regulation of Toughened Glass for Vehicles(GTR No. 6)

Global technical regulation No. 6

<A. STATEMENT OF TECHNICAL RATIONALE AND JUSTIFICATION>

30. The purpose of the 227 g steel ball test is to assess the resistance of the glazing to impacts from stones or other flying objects that might be encountered in everyday use.

<B. TEXT OF REGULATION>

3.3.7. **Uniformly toughened -glass** : means glazing consisting of a single layer of glass which has been subjected to special treatment **to increase its mechanical strength** and to condition its fragmentation after shattering.

6.3.4.1. The test pieces shall be flat samples measuring 300 x 300 mm, **specially made or cut** from the flattest part of a windscreen or pane.

6.3.4.2. Test pieces **can alternatively be finished products** that may be supported over the apparatus described in paragraph 6.3.1.

6.3.4.3. If the test pieces are curved, care should be taken to ensure adequate contact with the support.

6.3.2.3. The point of impact shall be within 25 mm of **the centre of the supported area** for a drop height less than or equal to 6 m, and within 50 mm of the centre of the supported area for a drop height greater than 6 m.

b. Analysis of GTR No. 6

The features of toughened glass for vehicles can be divided into two things. First, the external impact strength is three to four stronger than original glass. Second, when it is damaged it breaks into small pieces without sharp points.
GTR No. 6 provides a 227 g ball drop test to evaluate external impact strength, the feature of toughened glass, and fracture test to evaluate if it is broken into small pieces without sharp points.
The height of the ball drop test provided in GTR No. 6 is 2 m. This is lower than the height of damage of original glass in our test. Therefore, to evaluate the mechanical strength of toughened glass, setting the 227 g ball drop height as more than or equal to 3 m should be considered.
Also, if toughened glass has a ceramic-printed area, it cannot be regarded as equal to toughened glass. Therefore, the test method for ceramic-printed toughened glass needs to be provided separately.
For your reference, there is the item that heated wire installed in window glass is excluded from tests in UN Regulation No. 43, “Uniform provisions concerning the approval of safety glazing materials and their

installation on vehicles." It is considered that the device needed to secure a view rather than the strength of glass is allowable regardless of strength.

Regulations No. 43

<ANNEX 5>

3.1. 227g ball test
3.1.1. Indices of difficulty of the secondary characteristics.

Material	Index of difficulty	Colouring	Index of difficulty
Polished glass Float glass Sheet glass	2 1 1	Colourless tinted	1 2

The other secondary characteristic (**namely, incorporation or otherwise of conductors**)is not involved.

6. CONCLUSION

Ceramic printing technology, the surface process technology of toughened glass, was evaluated as an innovative technology when it was developed. It is said the development of this technology has reduced the production process for the attachment of window glass to vehicle bodies and improved durability. Also, the design of a vehicle body has freely gone luxe, and UV rays can be blocked. In this way, ceramic printing has a lot of benefits.
Because of these many benefits, the ceramic-printed area in the toughened glass has been broadened. In particular, as panoramic sunroof-equipped vehicles became popular, the ceramic area went bigger in design, and vehicles with ceramic-printed toughened glass account for as much as over 70% of vehicles.
However, it was confirmed that the ceramic-printed area of toughened glass has the drawback that its strength was lower than original glass, as shown in table 1 and Figure 3.
Therefore, as it is vulnerable to small external impacts or vibration, it leads to the damage of the whole toughened glass. In particular, in the case of a sunroof, which is installed above the head of a driver, if the glass is damaged, the glass fragments fall onto the head of the driver and threaten safe driving.
Hence, it is considered that if ceramic printing is necessary for toughened glass for a vehicle, it should be applied in the minimum area needed for the attachment of glass to the vehicle body.
The low strength of the ceramic printed area of toughened glass, which was determined in this study, is expected to be overcome through technology development for ceramic painting or various kinds of surface treatment technology. If it cannot be overcome with current technology, the safety regulation for window glass should be revised to minimize the risk. Therefore, it is believed that regulation of the ceramic-printed area of glass through the revision of the current regulation can contribute to safe driving.

RERERENCE

[1] Motor Vehicle Safety Standard of Korea, Article 34 "Window Glass", Article 105 "Stability of Window Glass"

[2] UN ECE Regulation No. 43 "UNIFORM PROVISIONS CONCERNING THE APPROVAL OF SAFETY CLAZING MATERIALS" Revision 1, Revision2 and Revision 3.

[3] FMVSS 571.205 Standard No. 205 "Glazing materials".

[4] SAE Standard ANSI / SAE Z26.1-1996.

[5] UN Global Technical Regulation No. 6 "SAFETY GLAZING MATERIALS FOR MOTOR VEHICLE AND MOTOR VEHICLE EQUIPMENT" 12 March 2008.

[6] KAC Homepage 'http://kac.kccworld.co.kr'

[7] HANGLAS Homepage ‘http://www.hanglas.co.kr/auto/’

[8] NSG Group Homepage ‘http://www.nsg.com/en/our-businesses/automotive’

THE AUSTRALIAN TERRAIN VEHICLE ASSESSMENT PROGRAM (ATVAP)

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ABSTRACT

Around 12 to 14 people are killed and 1400 injured annually in Australia resulting from Quad bike (All- Terrain Vehicle - ATV) and Side by Side Vehicle (SSV) incidents. The Australian Terrain Vehicle Assessment Program (ATVAP) consumer safety star rating system has been developed on the basis of a series of tests assessing a vehicle's static stability, dynamic handling and rollover crashworthiness and is being proposed as a method to reduce these serious and fatal injuries mainly resulting from Quad bike rollovers.

The ATVAP objective is to introduce a robust, test based rating system, in order to provide consumer based incentives for informed, safer and appropriate vehicle purchase, highlighting 'Fit For Purpose' criteria, with corresponding incentives and competition amongst the Quad-bike and SSV industry for improved designs and models. This paper presents an overview of the testing basis on which the proposed rating system was developed.

INTRODUCTION

Background

In Australia, the term for vehicles commonly used on farms over rougher terrains is Quad Bikes or Side-by-Side Vehicles (SSVs) depending on their size and farming task. Quad bikes (Figure 1: top left frame) are distinguished from SSVs (Figure 1: top right frame) in Australia by their design, namely the Quad bike's straddle seating, steering via handlebars with a small thumb operated throttle on the right side and low pressure tyres. This compares to the SSV's operator configuration which is more akin to a traditional car where seating is upright, a steering wheel is used to direct the vehicle, brakes and accelerator are operated by the drivers right foot and wheel tyre pressures are higher.

The Quad bike is called an All-Terrain Vehicle or ATV in the United States of America (USA). However, both an Australian Coroner and the USA Federal Government's Consumer Product Safety Commission (CPSC) have indicated that the term 'All-Terrain Vehicles' is misleading and may result in false assumptions as to the terrain that such vehicles can safely traverse [1, 2]. Hence, there is considerable resistance by Australian safety stakeholders in regards to the use of the term All-Terrain Vehicles or ATV. In this paper the term Quad bike will be used throughout to describe this vehicle type as shown in top left frame of Figure 1.

The SSV shown in the top right frame of Figure 1 is also referred to as a Recreational Off-Highway Vehicle (ROHV) in the USA. In this paper the term SSV will be used throughout to describe this vehicle type. Another term sometimes used in the USA for SSVs is Utility Task Vehicle (UTV). SSVs are distinguished from various larger four wheel drive or sports utility vehicles (SUV) off-road vehicles by their limited width, limited gross vehicle weight rating and limited engine capacity. However, the term All-Terrain Vehicle or ATV is sometimes used in Australia inadvertently to describe a SSV. One potential confusing factor in Australia is the continuing use of the terms 'Quad', 'Quad bike', 'ATV' and 'All-Terrain Vehicle' by the media, by accident investigators, by Coroners, and by others, which has often been used to refer to both Quad bikes and Side-by-Side Vehicles.

It is estimated that there were approximately 270,000 Quad bikes (ATVs) and SSVs in use in Australia in 2010 [3]. This compares to an estimated 80,000 Quad bikes and SSVs in use in New Zealand agriculture in 2010 [4]

and an estimated 10 million Quad bikes and SSVs in use by 16 million individuals in 2008 in the United States (US) [5]. However, SSVs are increasingly being used on farms and workplaces in place of Quad bikes, and are part of the 'Fit For Purpose' vehicle selection for farming and workplace environments being promoted by the Quad bike safety stakeholder groups. Some advantages of SSVs when compared to Quad bikes are: greater carrying capacity; standard driving configuration (e.g. steering wheel and pedals); no specific physical capacity for performing "active riding" as required with quad bikes; roll cages or rollover occupant protection systems; and, occupant restraint systems.

A detailed study of Australian fatalities from the Australian National Coronial Information System (NCIS) involving Quad-bikes and SSVs from 2001 to 2012 was carried out to establish injury mechanisms associated with their usage [6]. Around 141 fatalities were identified of which 109 were relevant to the study described here, and were studied in detail by the authors. Approximately 75% occurred on farms. A rollover occurred in 71% of all cases and of these 85% of the work related fatal cases involved a rollover compared to 56% of recreational cases. Around 28% involved mechanical asphyxia where 50% were 'pinned' by the Quad bike and for the 53 farm cases identified 68% were 'pinned'. Regarding Quad bike & SSV injuries, based on hospital and other injury databases [7], it is estimated that there are approximately 1,400 presentations per annum at hospitals in Australia, from minor to severe injuries.

In response to the incidence of fatal and serious injury rollovers involving Quad bikes it has been proposed by some authorities and other safety stakeholders that, as a minimum, Operator Protection Devices (OPDs) such as those devices highlighted by the Authors in a previous paper [8], be installed on all workplace Quad bikes. That proposal is based mainly on the observation that a two post Rollover Protection System (ROPS) fitted to old and new tractors has resulted in a marked reduction of tractor fatalities [9, 10, 11] and hence, by analogy, might be effective in reducing Quad bike rollover harm.

While in principle it appears that such systems may have a protective benefit in some rollovers, it is also clear that fitment of OPDs will not prevent rollovers from occurring in the first instance and OPDs may not be effective in all rollover situations [12], as active separation or ejection still occurs and impact or crush by stiff areas on the Quad bike or the OPD itself may result. Other than the reports by the Authors, Australian research on the 'in service' effectiveness of OPDs based on fatality and hospital data has yet to be done. Some USA research has been done and published based predominantly on computer simulations and some limited field rollover tests on full ROPS designs [13-19], but similarly no US cohort studies have been carried out to assess the effectiveness of OPDs in the field or laboratory tests of Quad bikes fitted with an OPD.

Thus, there has been little agreement on the way forward in improving Quad bike safety in regard to rollover [20]. The Australian Industry manufacturers represented by the Federal Chamber of Automotive Industries (FCAI) policy position for Quad bikes is that while some design and safety performance measures have been standardised and introduced (mandatory under US law), they remain focused on rider training, active riding and administrative controls such as personal protection equipment (PPE), e.g. such as helmets [8].

The Authors note that in the hierarchy of control measures for managing risks, engineering controls which design out the hazard are considered a more effective control measure than training courses which seek to change human behaviour. The authors note from Australian regulations covering mobile plant and structures in Australia, that persons with management or control of plant at a workplace are required to prevent mobile plant from overturning or the operator from being ejected from the plant. This person(s) must ensure, so far as is reasonably practicable, that a suitable combination of operator protective devices (OPD) for the plant is provided, maintained and used. A person who neglects their 'duty of care' to prevent mobile plant from overturning or the operator from being ejected from the plant, can be criminally charged in the event of serious injury or death of an employee.

Increasing rollover resistance and enhancing rollover crashworthiness design, should be one of the first components in the hierarchy of controls for managing risks within a Safe System Approach [21] in the workplace. Control should include engineering approaches, e.g. increasing rollover resistance and enhancing rollover crashworthiness design, while still maintaining the operational capabilities of the vehicles. Nevertheless, the authors also support administrative controls, but as a complimentary component of a larger holistic Safe System Approach based on the Swedish 'Vision Zero' criteria (i.e., no deaths in the workplace). Even higher-level controls in work situations would be to (a) ban quad bikes and/or (b) substitute SSVs for Quad bikes.

Administrative controls are generally accepted as the lesser effective form of control in a Vision Zero (no deaths) Safe System Approach, in the hierarchy of safety controls. Nevertheless, the Industry (FCAI) have advised the Authors that:

"In the USA, where since 1991 the only increases in control have been in administrative controls (i.e., increasing passage of state laws regarding Quad bike usage, increasing to 47 out of 50 states as of 2013), during 1999 – 2006 Quad bike fatality rates (per 10,000 vehicles in use) decreased by 29%, and during 2001-2010, Quad bike emergency department rates (per 10,000 vehicles in use) decreased by 56% (Garland (2011, Tables 4 and 7) [22]*, demonstrating the effectiveness of administrative controls."*

However, this statement fails to recognise the significant limitations that the CPSC note in all their reports regarding collection of fatality and injury data and the number of vehicles in use. Whilst the authors agree with the Quad bike Industry (FCAI) regarding their call for further in-depth research of injury and vehicle data relating the characteristics of Quad bike and SSV rollover crashes in general and also in relation to vehicle stability, handling and crashworthiness design would be of benefit, the authors disagree that vehicle design safety advances cannot proceed until such data is fully obtained and analysed. This argument should not be used to hinder safety design advancement for Quad bikes and SSVs. The authors consider that until such data can be obtained, the principles established over the past 50 years in mobility safety for all vehicle types can be usefully and appropriately applied to Quad bike and SSV safety design.

For this reason, Australian users of Quad bikes, farm safety stakeholder groups, government occupational health and safety regulators, and safety researchers, see from the history of safety advances in road vehicle transport that design countermeasures are possible, practical and effective, and that fitment of OPDs to Quad bikes is seen as a means of harm minimisation. In contrast, the Quad bike Industry (FCAI) continues to negate promotion of any design solutions concerning fitment of OPDs. The Quad bike Industry's resistance to fitment of OPDs (in their view) is that there is no scientifically valid 'in service' research data indicating that fitment of OPDs would be effective, not harmful and not compromising the capabilities of the vehicle. Hence, there exists a decades-long impasse on advancing Quad bike rollover crashworthiness safety and the need for a new approach, as a way ahead to reduce Quad bike trauma until such data is collected [8].

What is clear is that rollover is a major contributor to fatal and serious injury outcomes involving Quad bikes and SSVs, and therefore measures aimed at reducing both the incidence and severity of rollover are obvious injury prevention countermeasures that should be strongly advanced. The authors do not agree with Industry (FCAI) that Quad bikes and SSVs are exempt from such fundamental safety principles which apply to all mobile vehicles that transport people (e.g., cars, trucks, trains, trams, buses, motorcycles, bicycles, etc.). A pro-active approach should be taken rather than waiting another decade until such in-depth data may become available, with many additional casualties occurring as a consequence of such delays. We are reminded here of the wise aphorism "Do not let the *best* be the enemy of the *good*", with regard to progressing Quad bike and SSV safety.

On this basis, in order to assist consumers and workplace plant managers to address their current technical and political challenges to improving the design of Quad bikes and SSVs in regards to rollover safety, particularly in the farm environment, the Australian Terrain Vehicle Assessment Program (ATVAP) Star Rating System for Quad bikes and SSVs was developed. While clearly the authors make no claim that a 'newly-born' ATVAP can draw on a long and well validated history, as can the NCAP (worldwide New Car Assessment Programs), with its now 36 years history of development, innovation and robust validation (NCAP, started in the USA in 1978), it is apparent that such testing based star rating system for consumer information has been a major catalyst for and helped promote large technological safety advances in automobile safety [23].

The objective is to introduce a robust, test based rating system, in order to provide workplace and consumer based incentives for informed, safer and appropriate vehicle purchase (highlighting 'Fit For Purpose' criteria), and at the same time generate corresponding incentives and competition amongst the Quad bike Industry for improved designs and models for the workplace environment. The premise is that Quad bikes and SSVs with a higher resistance to rollover and improved rollover crashworthiness will result in reduced rollover related fatalities and serious injuries. It is proposed that those vehicles receiving high stability and crashworthiness overall rating index values, will in fact be found to have lower fatality and serious injury rates as has occurred with other vehicle types [24, 25]. This opinion takes its basis from the NCIS Coronial data [6], which indicates overwhelmingly that rollover, pinned entrapment and asphyxiation are the major casual factors involved in farm place deaths related to Quad bikes. It is hoped that ATVAP will be implemented in Australia (and internationally) to provide design safety gains for Quad bikes, SSVs and similar type vehicles for farm, workplace and indeed eventually in recreation use, over the years as it matures and accumulates further real world data to provide appropriate development, validation and refinement.

The following sections provide an overview of the components of the ATVAP rating system.

ATVAP METHOD

The Australian national Heads of Workplace Safety Authorities (HWSA) committee identified in 2011 Quad bike safety to be a major issue on farms in Australia and New Zealand. As a result the ATVAP Star Rating method was developed within a major program of tests, namely the Quad bike Performance Project (QBPP), managed and carried out at the TARS unit at the University of New South Wales (NSW), Australia [26]. The QBPP was funded by the New South Wales Workcover Authority with a contribution from the Australian Competition and Consumer Commission (ACCC). The series of tests were carried out on a selection of 16 production vehicles consisting of 8 Quad bikes, 3 recreational Quad bikes and 5 SSVs. Testing was carried out at the NSW state government's Roads and Maritime Services Crashlab crash testing facility. The test program essentially consisted of three Parts, namely, Part 1: Static tests, Part 2: Dynamic handling tests and Part 3: Rollover crashworthiness tests.

While initially, the project was limited to testing Quad bikes only, it became apparent early in the test program that it would have been far too limiting in scope to simply restrict testing to only Quad-bikes, and that Side by Side vehicles (SSVs) should also be included as they were increasingly being used on farms and as possible safer alternatives to Quad bikes. This was a fundamental (yet still controversial to some) decision made early in the program to expand the mix of 'workplace' and 'recreational' Quad bikes and SSVs. This was also the first time that such a comparison of vehicle stability, handling and crashworthiness has been made across such a diverse range of terrain vehicle types. This decision has proven to be valid and invaluable. It has enabled the focus of the testing to broaden from just considering what improvements to Quad bikes could be made by manufacturers. What has resulted is a much more fundamental approach to risk reduction/management options involving, in principle, appropriate vehicle selection and 'fitness for purpose' criteria, and provision of previously unavailable comparison of Star Rating information for Quad bikes and SSVs for consumers. Hence, the ATVAP rating should be of both Quad bikes and SSVs compared together.

Part 1 - Static Stability Tests.

Static Stability tests provide the first arm of the assessment and rating of Quad bikes and SSVs for rollover propensity (Figure 1). This test series should be comprised of tilt table tests for rollover resistance in lateral roll,

Figure 1: Photographs from the tilt table tests, showing Quad bike with ATD for a lateral roll tests, and SSV for lateral roll, rear and forward pitch tests.

forward and rearward pitch. The tests use a 95th percentile Hybrid III Anthropomorphic Crash Test Dummy (ATD) as a surrogate rider with a test mass of 103kg. The test matrix should include the vehicle on its own and then with a rider, and with combinations of maximum cargo loads on the front and rear. The Tilt Table Ratio (TTR), which is approximately the Tan of the angle of the tilt table shown in Figure 1, from the project tests for the Quad bikes, ranged from as low as 0.41 to at most 0.6 in the lateral roll direction with the ATD seated on the vehicle. The TTR for the SSVs were notably higher than for the Quad bikes, on the other hand, and ranged from 0.64 to 0.96 in the same (lateral) roll direction also with the same ATD. It was also found that OPDs had little effect on static stability measures.

It is important to highlight that a relative index which compares one vehicle with another should be developed. As such no one vehicle is then being disadvantaged against another as the same criteria and weighting is applied to all vehicles. Preliminary parametric analyses of the effect of any weighting variations from the test program [27] indicate that the relative static stability index of one vehicle compared with another is relatively insensitive to such variations. The stability indices are firstly based on the TTR values for each of three tilt test directions, by summing and then averaging the TTR values for each loading combination within those test directions:

1. Lateral Roll
2. Forward Pitch
3. Rear Pitch

The final Static Stability Overall Rating Index for each vehicle is then derived from weighted average TTR values for each of the three test directions.

In order to show a perspective regarding the stability of Quad bikes and SSVs in the lateral roll direction, Figure 2 provides a comparison of the author's postulated rollover crash rate versus Static Stability Factor (SSF) for Quad Bikes and SSVs compared to NHTSA's Mengert (1989) rollover crash rates for cars and SUVs [24], and New Zealand's (DIER, 2006) rollover crash rates for heavy articulated and rigid trucks [25]. Figure 2 is essentially a composite with the addition of the author's postulated curve, showing the relationship between the TTRs measured for Quad bikes and SSVs [26, 27] versus relative rollover crash rate. Furthermore, Figure 2 shows that the stability of Quad bike's TTR (SSF and TTR are similar measures) is in the lower range and not dissimilar to trucks; whereas the TTR (SSF) for higher stability SSVs overlaps with a four wheel drive/ Sports Utility Vehicles (SUVs). The authors postulate that the likely rollover risk for lower stability Quad bikes could be as much as four times (or higher) as the highest stability SSVs. Better data collection is required for Quad bike and SSV crashes to determine the actual rollover risk curve for these vehicles, as has been done for the other motor vehicle types.

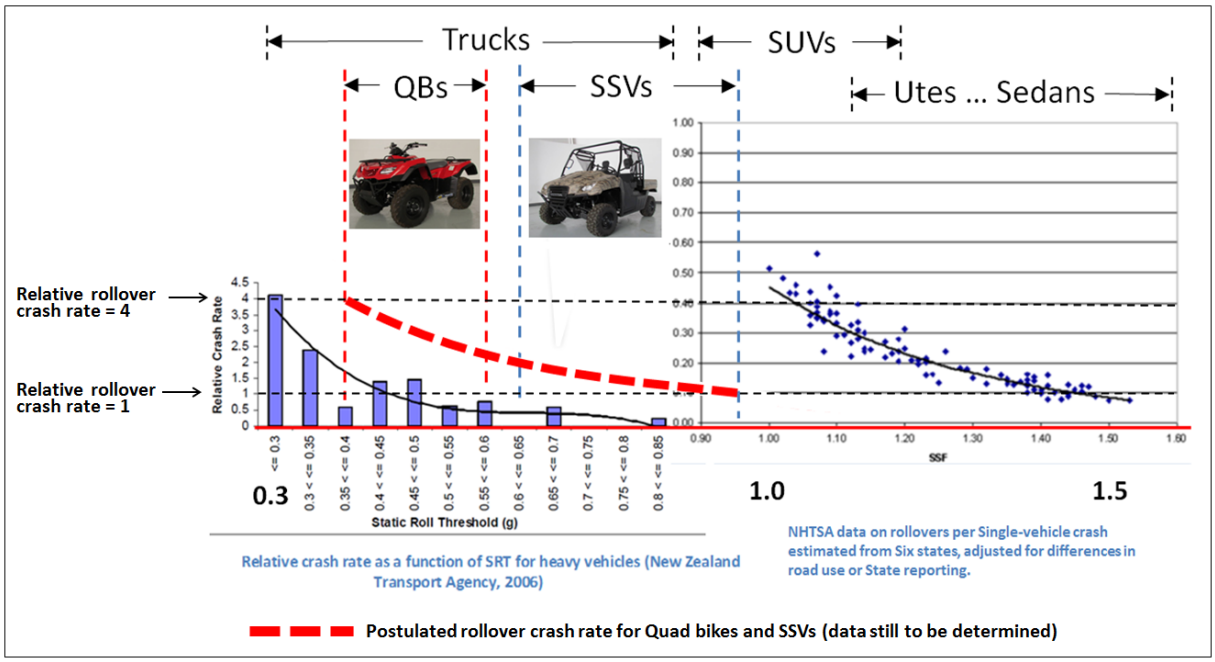

Figure 2: The Author's postulated crash rate versus Static Roll Threshold (SSF ≈ TTR) for Quad Bikes and SSVs with rider/driver (with 95th% ATD) compared to NHTSA's Mengert chart for relative rollover crash risk for cars and SUVs [24] and to New Zealand Transport Agency's Relative Rollover crash rate for trucks [25].

Hence, the authors are of the opinion that history has clearly demonstrated that advances in safety for all types of land mobile vehicles are correlated with improvements in stability, handling and crashworthiness. There is no reason why Quad bikes and SSVs should be any different and not obey the same laws of physics and vehicle dynamics.

Part 2 - Dynamic Handling Tests.

This Part was comprised of dynamic handling tests [Figure 3] which included the ISO 4138: 2012 Passenger Cars - Steady State Circular Driving test method and the ISO 7401: 2011 Road Vehicles - Lateral Transient Response – open loop test method [28]. Both these test methods were modified for a Quad bike and a SSV. An obstacle perturbation bump test (simulating riding one side over a rock like object) was also included and is presented in a companion ESV paper [29]. Components of these dynamic handling tests complemented the static stability evaluation.

The proposed Dynamic Handling Overall Rating Index is based on the summation of the Index values from the following four dynamic test results with rider/ driver for each vehicle:

1. **Steady-state circular driving behaviour dynamic tests** - the limit of lateral acceleration, Ay (g)
2. **Steady-state circular driving behaviour dynamic tests** - scores either the understeer or oversteer characteristic. The point of transition between understeer and oversteer is also rated.
3. **Lateral transient response dynamic tests** - the steering response time.
4. **Bump obstacle perturbation tests** - the measured acceleration of the ATD pelvis.

Figure 3 shows the test setup for both the Quad-bikes and the SSVs. The circular tests provide information on the vehicle's limit of lateral acceleration and whether it has an understeer, oversteer or neutral steering characteristic, and the point of transition between them, if it transitioned from one characteristic to another. The step steer response tests provide information on the vehicle's lateral transient response time. The perturbation bump test provided information on pitch and yaw response and how much the perturbation disturbs and displaces the rider from their riding position. Details of the tests and results and how the vehicles were rated are presented in [28].

The focus of the dynamic handling rating index is to encourage those dynamic characteristics that provide predictable and forgiving handling characteristics while remaining responsive and highly mobile in a farming and workplace environment. Moreover, in order to provide predictable and forgiving handling characteristics while remaining responsive and highly mobile, in the author's opinion a vehicle should be designed to provide a light understeer response of between 1 to 2 degrees per g lateral acceleration. In light off-road vehicles, this understeer characteristic should continue to at least 0.5g lateral acceleration. Those vehicles that demonstrated this characteristic are provided with a higher rating Index value.

Most Quad bikes had a fixed rear differential, which meant that the rear wheels rotated in unison, even when on a curve. Most SSVs that had an open differential (or the option to switch from an open to fixed differential and vice versa), all exhibited light understeer handling characteristics. When the rear differential was locked, the vehicle demonstrated oversteer characteristics. For those that had an open differential did not tip but either simply broke traction on the rear inside wheel and reduced speed or slid out, under the test conditions.

Part 3 - Rollover Crashworthiness Tests.

This Part of the proposed ATVAP was comprised of tests that focused mainly on rollover crashworthiness. Some exploratory testing and procedures were carried out for the purposes of developing a rollover crashworthiness rating (see: Figures 4 and 5). A Motorcycle 50th % ATD (MATD) was used as the rider/driver in the exploratory rollover crashworthiness tests that were undertaken for the purposes of developing the rollover crashworthiness rating Index. The MATD is based on the HIII ATD but with enhanced features.

The tests carried out were:

1. Measurements of static ground contact force for a Quad bike with and without an OPD on its left and right side and when inverted (Figure 4: top left frame). The mass difference between different model Quad bikes was not sufficient to provide significant discrimination in terms of asphyxia potential [6, 26], as in most cases the 50 kg asphyxia load criterion would be exceeded.
2. Inspection and measurements of Side by Side Vehicle (SSV) occupant retention (Figure 4: top right frame) in accordance with the United States (US) American National Standard for Recreational Off-

Figure 3: Steady state circle testing on asphalt and on grass. Top left: Rider on Quad bike following circle. Top right: Rider on Quad bike following grass circle at point of tilt. 2nd row: Grass circle test site 3rd row: Typical Quad bike circular driving behaviour test where both wheels lifted. Bottom: An SSV that was tested with outrigger wheels fitted.

Figure 4: Examples of: 1. (top left) Quad bike contact force tests using load scales; 2. (top right) Side-by-Side Vehicle occupant retention; 3. (bottom left) SSV Roll-Over Protective Structure (ROPS) lateral pull test; and 4. (bottom right) Rollover test with occupant and Lifeguard OPD.

Highway Vehicles ANSI/ROHVA 1-2011 with additional constraint requirements applied [30], i.e. points are deducted if there is extension of any part of the ATD outside the plane of the vehicle width when the vehicle is tilted over on the tilt table; and the seat belts in all seats are not a 3 point seat belt or harness (4 or 5 point). Bonus points are awarded if there is a seat belt warning light which switches off when the seat belt is locked in, for a seat belt audible alarm that is maintained for at least 5 minutes when a person is seated in the vehicle and turns off when the seat belt is locked in, and for a seat belt interlock system that is ignition or speed interlock based.

3. SSV ROPS structure load tests consisting of applying a lateral load (Figure 4: bottom left frame) followed by a vertical load then a longitudinal load to the vehicle ROPS whilst recording the deflection and noting the structural integrity, in accordance with the ISO (2008) test option [31] for the US ANSI/ROHVA 1-2011 requirements [30].
4. Vehicle and rider/driver dynamic rollover tests consisting of positioning a MATD in the operator's position of a Quad bike or Side by Side Vehicle, tilting the vehicle to an angle at which rollover would occur, and releasing the vehicle from an initial static position to rollover to observe 'survival space' and functionality of the OPD (Figure 5), and in the case of the SSVs the ROPS and restraints (Figure 4: top right frame). Lateral roll (Figure 5), forward pitch (Figure 4: bottom right frame) and rearward pitch was carried out for the Quad bike. Two SSVs were also tested in lateral roll.

It became apparent that it was unrealistic currently to be able to discriminate the rollover crashworthiness between different Quad bike models [32]. However, discrimination between vehicle types, e.g. Quad bikes and SSVs, was realistic. Further, it was also evident from preliminary rollover, forward pitch and rearward pitch testing, that due to the stochastic ('hit and miss') nature of severe injury risk to a rider and the large range of possible relevant rollover test permutations, it was unrealistic to continue with such tests for rating Quad bikes. Indeed it was deemed by the authors that the term "Crashworthy Quad bike" was essentially a contradiction in terms. For this reason for the Quad bike type, all were assumed to be rated equally for rollover crashworthiness, and all were assigned the same arbitrarily low minimum value points rating when assessing rollover

Lateral roll without OPD

Forward pitch with Quadbar

Lateral roll with Lifeguard OPD

Lateral roll with Quadbar

Forward pitch roll - No OPD

Figure 5: Examples of Quad bike lateral rollover and forward pitch tests with and without OPDs [32]. For more details see 'Part 3: Rollover Crashworthiness Test Results' report.

crashworthiness protection. Fundamentally Quad bikes do not and cannot satisfy fully the well-known principles of occupant protection in rollover crashes even with an OPD attached, i.e. good containment and crush prevention. If the straddle position is maintained with respect to the vehicle's design and 'separation' is the crashworthiness criterion adopted by the Industry (FCAI) then it is unlikely the Quad bikes would not achieve any points higher than the lowest range (approximately 1/5th of maximum score). The main reason the Quad bikes can be allocated some points even though they were at the lowest range of values, is that riders have survived when a Quad bike has rolled and indeed when the vehicle has rolled over the rider.

In contrast to Quad bikes, the SSVs do adhere in general to rollover crashworthiness principles, in that they are typically fitted with ROPS, seatbelts and various degrees of containment measures which combine to keep the occupants within a protected space. As the effectiveness of such designs in terms of severe injury prevention can vary widely, it is possible to discriminate and rate SSVs. Hence, the rollover crashworthiness of SSVs tested were evaluated against the ANSI/ROHVA standard [30] and fundamental crashworthiness principles of rider/occupant protection in rollovers. In contrast to the Quad bikes, well designed SSVs offer superior rollover crash protection in a typical farming environment. This is provided that three point (or harness) seatbelts and helmets are worn and other occupant lateral restraints are fitted and are in place, e.g. doors, side meshing, etc. The results from the rollover crashworthiness tests provide sufficient discrimination in the range of vehicles tested (Quad bikes and SSVs) to use as a basis for the rollover safety rating system.

The ATVAP Star Rating System

The Star Rating is the sum of the points for the three tests (Parts 1 to 3), with equal points allocated to each test performance requirement, i.e. Static stability, Dynamic Handling and Rollover Crashworthiness. Additional bonus points (approximately 10% to 15%) can be provided for vehicles that have an open rear differential, both a seat belt warning light and audible sound which turns off when the seat belt is locked in, and a seat belt interlock which either prevents vehicle startup or restricts the maximum speed of the vehicle to around 5 to10 km/h.

Figure 6 shows the final graph of the 16 production vehicles tested in the Quad Bike Performance Project albeit the particular models have been masked at this point in time. The graph shows that the SSVs outperformed the Quad bikes significantly. The star rating shows that the SSVs demonstrated superior static stability (see Figure 2), superior dynamic handling reflecting a slight understeer characteristic, minimal disturbance of steering in the bump test [29], and superior rollover crashworthiness, when compared to the Quad bikes. The Recreational Quad bikes have no physical provision (e.g. load rack, etc.) to carry loads. Two of these vehicles (3 star) demonstrated superior static stability and dynamic handling characteristics indicating these design features can be improved for Quad bikes. For SSVs, it is however vital to recognize, that as with passenger vehicles, the significant variation in the Star rating between different SSVs.

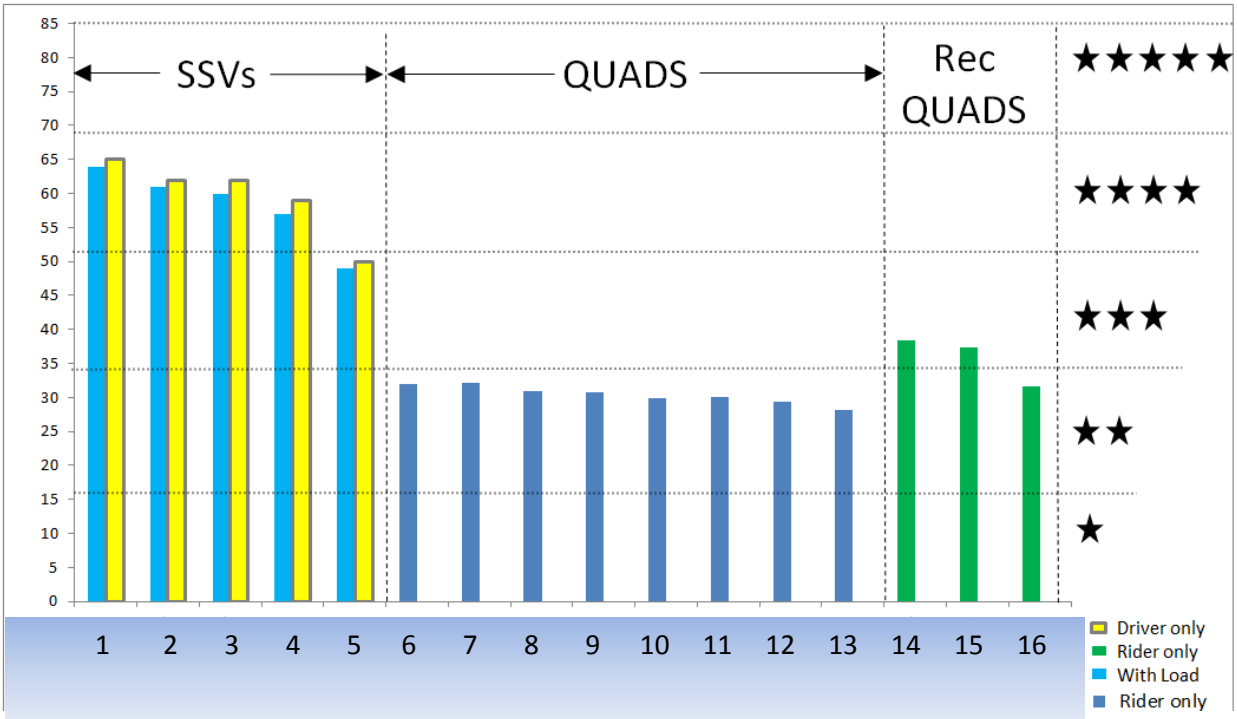

Figure 6: Final Points and Star Rating of the 16 production Quad bikes and SSVs tested.

CONCLUSIONS

The aims of the project were to also introduce a robust, test based Star Rating system, similar to other product rating systems, in order to provide consumer based incentives (and assist workplace plant managers) for informed, safer and appropriate vehicle purchase (highlighting 'Fit For Purpose' criteria) that reduced the risk of being injured in a rollover in a workplace setting, and at the same time generate corresponding incentives and competition amongst the Quad bike and SSV Industry for improved designs and models. Those aims were met. It was possible to develop a Star Rating system, that was capable of providing sufficient discrimination in the range of vehicles tested and commonly used, (Quad bikes and SSVs) as a basis for consumers to be able to choose a vehicle that provides a lower risk of rollover, and lower risk of injury if the vehicle does roll.

There are no standards or compliance requirements in Australia for Quad bikes or SSVs. The proposed Australian Terrain Vehicle Assessment Program (ATVAP) consumer Star Rating system presented provides a rapid means of applying a performance benchmark testing protocol that can lead to significantly reduce rollover injury risk. Using the Star Rating system, manufacturers would be encouraged to compete with each other in order to make their products attractive to potential consumers and workplace plant managers wanting to purchase a safer workplace/farming vehicle and comply with workplace regulations.

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REFERENCES

[1] Olle J, (2009). Investigation into deaths of Vince Tobin, Joseph Jarvis Shepherd, Jye Kaden Jones, Peter Vaughn Crole, Thomas James Scutchings, John Neville Nash, Patricia Murray Simpson, Elijah Simpson with inquest, Melbourne: State Coroner Victoria, Australia.

[2] Elder J, Leland E, (2006). CPSC Staff Response Regarding Follow-Up Questions from Commissioner Moore after the June 15, 2006, ATV Safety Review Briefing, in editor: http://www.cpsc.gov/LIBRARY/FOIA/FOIA06/brief/atvmoore.pdf

[3] Australian ATV Distributors, Australian ATV Distributors position paper, January, 2010. http://www.fcai.com.au/library/publication/1302069213_document_5_january_2010_industry_position_paper.pdf

[4] Carman A., Gillespie S., Jones K., Mackay J., Wallis G., and Milosavljevic S., All terrain vehicle loss of control events in agriculture: Contribution of pitch, roll and velocity. Ergonomics, 2010. 53(1): p. 18-29.

[5] Helmkamp, J., Marsh, S., and Aikten, M., Occupational all-terrain vehicle deaths among workers 18 years and older in the United States, 1992-2007. Journal of Agricultural Safety and Health, 2011. 17(2): p. 147-155.

[6] Grzebieta R.H., Rechnitzer G., McIntosh A., Mitchell R., Patton D., and Simmons K., (2014). Investigation and Analysis of Quad Bike and Side By Side (SSV) Fatalities and Injuries, Quad Bike Performance Project (QBPP) Report 3-2014: Supplemental Report, Transport and Road Safety (TARS) Research Report, submitted to The WorkCover Authority of New South Wales, University of New South Wales, Sydney, Australia.

[7] Mitchell R. Grzebieta R. Rechnitzer G., Capture and surveillance of quad bike-related injuries in administrative data collections. International Journal of Injury Control and Safety Promotion, published on-line January 7, 2015. DOI:10.1080/17457300.2014.992353.

[8] Rechnitzer G, Grzebieta R, McIntosh A, Simmons K. (2013). Reducing All Terrain Vehicle Injuries (ATVs) and Deaths - A Way Ahead, presented at the 23rd International Technical Conference on the Enhanced Safety of Vehicles, Seoul, South Korea, 2013.

[9] Day L & Rechnitzer G, Evaluation of the Tractor Rollover protective Structure Rebate Scheme, May 1999, Monash University Accident Research Centre. Report 155.

[10] Scott M., Willaims R., Day L., Rechnitzer G., Walsh P., and Boyle S., 2002. Safe Tractor Assessment Rating System, Technical Reference Documant, Monash University Accident Research Centre and Kondinin Group.

[11] Franklin R.C., Stark K.L. and Fragar L.J., (2005). Evaluation of the New South Wales Rollover Protective Structure Rebate Scheme 2000 - 2004. Australian Centre for Agricultural Health and Safety (ACAHS), University of Sydney, Moree.

[12] Grzebieta R.H. and Achilles T., (2007). Report on Quad-bar in Relation to ATV Rollover Crashworthiness, submitted to Victorian Coroner Inquest into ATV deaths, Dept. Civil Engineering, Monash University, Victoria, Australia.

[13] Van Auken R.M. and Zellner J.W., Preliminary Analysis of the Effects of ATV ROPS on Rider Injury Potential, Volume 1: Technical Report, DRI-TR-96-4B, October 1996, Second Revision Issued February 1997, Dynamic Research, Inc., California, USA.

[14] Van Auken, R.M., and Zellner, J.W., ATV ROPS/CPD Tests and Simulations, Dynamic Research, Inc. Technical Report DRI-TR-98-2, October 1998.

[15] Zellner JW, Kebschull SA, Van Auken RM, Lenkeit JF, Broen PC, (2004). Review And Analysis Of MUARC Report "ATV Injuries And Deaths," And Additional Simulation And Initial Testing of MUARC ATV Rollover Protection System (ROPS), Volumes I to III, Report submitted to Victorian Coroner Inquest into ATV deaths, Dynamic Research Inc.

[16] Zellner JW, Kebschull SA & Van Auken RM, (2006). Updated Injury Risk/Benefit Analysis Of Quadbar Crush Protection Device (CPD) For All-Terrain Vehicles (ATVs); DRI-TR-12-06.

[17] Zellner, J., Kebschull, S., and Van Auken, R., (2013), Evaluation of Injury Risks and Benefits of a Crush Protection Device (CPD) for All-Terrain Vehicles (ATVs)," SAE Int. J. Passeng. Cars – Electron. Electr. Syst. 7(1):2014, pp 41-72, doi: 10.4271/2013-32-9173.

[18] Grzebieta RH, Rechnitzer G, Richardson S, (2005). Comments on video evidence of rollover tests presented by Breen; Calculations regarding additional weight to ROPS to account for increased weight of ROPS; and Brief statement regarding human impact and acceleration [G-force] tolerance, Supplementary Report submitted to Victorian Coroner Inquest into ATV deaths, DVExperts International Pty Ltd.

[19] Van Ee C., Toomey D. and Moroski-Browne B., (2012). ATV Rollover, Operator Response, and Determinants of Injury: Implications for CPDs, Design Research Engineering. Presentation made at US Consumer Product Safety Commission ATV Safety Summit, Bethesda, USA, October.

[20] FCAI, (2012). ATV Industry opposes rollover devices on safety grounds. http://www.fcai.com.au/news/news/all/all/311/atv-industry-opposes-rollover-devices-on-safety-grounds.

[21] Grzebieta R.H., Mooren L., and Job S., Introduction (or Reintroduction) to the Safe System Approach, Roadside Safety Design and Devices, International Workshop July 17, 2012, Milan, Italy, Ed. R. Troutbeck, Transportation Research Board, Washington DC, Transportation Research Circular Number E-C172, February 2013, http://onlinepubs.trb.org/onlinepubs/circulars/ec172.pdf.

[22] Garland S. 2010 Annual report of ATV-related Deaths and Injuries. Bethesda, MD: Consumer Product Safety Commission, 2011.

[23] Paine M, and Haley J, (2008). Crash testing for safety - possible enhancements to ANCAP test and rating methods, Proc. 2008 Australasian Road Safety Research, Policing and Education Conference, Adelaide, South Australia.

[24] Mengert, P., Salvatore, S., DiSario, R., Walter, R., Statistical estimation of rollover risk, DOT-HS-807-466, U.S. Department of Transportation, August, 1989.

[25] Department of Infrastructure, Energy and Resources (DIER), Land Transport Safety Authority, SRT Calculator User Guide, TERNZ Ltd, Manukau, New Zealand, 25 May 2006. http://fuelsaver.govt.nz/srt-calculator/user-guide.pdf

[26] Grzebieta R, Rechnitzer G, Simmons K and McIntosh AS (2015) Final Summary Project Report: Test Results, Conclusions, and Recommendations, Quad Bike Performance Project TARS Research Report No 4, submitted to the WorkCover Authority of New South Wales, University of New South Wales, Sydney, Australia.

[27] Grzebieta R, Rechnitzer G, Simmons K. (2015) Static Stability Test Results, Quad Bike Performance Project TARS Research Report No 1, submitted to the WorkCover Authority of New South Wales, University of New South Wales, Sydney, Australia.

[28] Grzebieta R, Rechnitzer G, Simmons K. (2015) Dynamic Handling Test Results, Quad Bike Performance Project TARS Research Report No 2, submitted to the WorkCover Authority of New South Wales, University of New South Wales, Sydney, Australia.

[29] Hicks D., Mongiardini M., Grzebieta R, Rechnitzer G, and Simmons K, (2015). Analysis Of Quad-Bike Loss-Of-Control Using Experimental And Simulated Dynamic Bump Tests, Proc. 24th Enhanced Safety of Vehicles (ESV) Conference, Gothenburg, Sweden, Paper No. 15-0133.

[30] Recreational Off-Highway Vehicle Association, (2011). American National Standard for Recreational Off-Highway Vehicles, ANSI/ROHVA 1 - 2011, Recreational Off-Highway Vehicle Association, California, USA.

[31] International Standard (ISO), ISO 3471:2008(E), Fourth edition 2008-08-15, Earth-moving machinery - Roll Over protective structures - Laboratory tests and performance requirements.

[32] Grzebieta R, Rechnitzer G, McIntosh A. (2015) Rollover Crashworthiness Test Results, Quad Bike Performance Project TARS Research Report No 3, submitted to the WorkCover Authority of New South Wales, University of New South Wales, Sydney, Australia.

CONSUMER RESPONSE TO VEHICLE SAFETY RATINGS

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ABSTRACT

This study assessed how the release of the Insurance Institute for Highway Safety's (IIHS) new crashworthiness ratings based on a small overlap front crash configuration and ratings of front crash prevention systems affected consumer behavior. Telephone surveys were conducted with U.S. Volvo dealers after the August 2012 inaugural release of the IIHS small overlap frontal crash test ratings, in which the Volvo S60 was one of two models receiving the highest rating of good, and with U.S. Subaru and Jeep dealers after the May 2013 release of small overlap frontal test ratings of small SUVs, in which the Subaru Forester was the only model rated good and the Jeep Patriot was rated poor. Additional surveys were conducted following the September 2013 inaugural release of IIHS's front crash prevention ratings with U.S. Subaru, Volvo, and Cadillac dealers, automakers that offered automatic emergency braking systems receiving the top superior rating; U.S. Ford dealers, which offered a forward collision warning system rated basic; and U.S. Hyundai dealers, which had no rated system and offered little collision avoidance technology at the time.

Nearly half of Volvo dealers and 75% of Subaru dealers reported increased consumer interest in the S60 and Forester models, respectively, after their good ratings in the small overlap frontal test were broadcast. Volvo dealers reported a 41% increase in sales of the S60 and an 18% increase in sales of all Volvo models the week following this announcement compared with the week before. Subaru dealers reported a 14% increase in sales of the Forester and an 11% increase in all Subaru models compared with the week before the announcement, while Jeep Patriot sales declined slightly and sales of all Jeep models were essentially unchanged. About a third of Subaru, Volvo, and Cadillac dealers and 10% of Ford dealers reported increased consumer interest in front crash prevention systems after the inaugural ratings were released. Sales for all surveyed automakers declined from the week before the front crash prevention rating announcement to the following week. However, sales of Subaru, Volvo, Cadillac, and Ford models with rated systems declined 41% less than sales of Hyundai models, and sales of all models from these automakers declined 6% less than sales of Hyundai models. The findings suggest that well-publicized safety ratings can translate directly into changes in consumer vehicles purchases.

INTRODUCTION

Surveys of the public [1-5] and of recent new vehicle buyers [6] in the United States, Canada, and Europe conducted during the past decade have found that consumers find safety to be an important consideration when purchasing a new vehicle. About half of drivers surveyed in the United States [4] and Europe [3] reported they have researched the protection vehicles would provide in a crash, or that such information has been useful to them in choosing a new vehicle to purchase. Drivers also consider technology that improves vehicle safety when choosing vehicles. In a survey of U.S. vehicle owners [2], 58% reported that a vehicle having proven and tested technology was highly influential in new vehicle purchases. Approximately half said they would be willing to pay extra for enhanced safety features in vehicles.

The Insurance Institute for Highway Safety (IIHS) has provided information to U.S. consumers about vehicle safety since the mid-1990s. IIHS introduced a new vehicle crashworthiness test, the small overlap frontal crash test, in 2012. The test is designed to replicate the vehicle damage and motion that occurs in a collision where a small

portion of the vehicle's front end contacts the struck object, such as when the front corner of a vehicle collides with another vehicle, or when a vehicle strikes a tree or utility pole. In the test, 25% of a vehicle's front end on the driver side is crashed into a rigid barrier at 64 km/h. Compared with the moderate overlap frontal crash test, involving 40% of the vehicle's front end, the small overlap test puts higher stress on the outer part of the vehicle's safety cage, which typically is less protected by the vehicle's crush zone structures. The top rating possible in this and IIHS's other crashworthiness tests is good, followed by acceptable, marginal, and poor ratings.

IIHS expanded its vehicle ratings program in 2013 to include front crash prevention systems. Vehicles that brake autonomously in the event of an imminent frontal collision can earn ratings of advanced or superior based on performance in tests conducted at 20 and 40 km/h. For the top rating of superior, vehicles with autobrake must avoid a crash or reduce speeds substantially in both tests. For a rating of advanced, vehicles with autobrake must avoid a crash or reduce speeds by at least 10 km/h in at least one of the two tests. Vehicles earn a rating of basic if they have a forward collision warning system that meets National Highway Traffic Safety Administration performance criteria.

New IIHS vehicle safety ratings are typically publicized to the U.S. public through hundreds and thousands of television broadcasts and extensive coverage by print and internet news media. Although there is evidence that many consumers factor safety ratings into their vehicle purchase decisions, it is unknown how safety ratings translate into sales of specific models that receive high and low ratings. To investigate this, IIHS conducted three surveys of dealers about consumer interest in and sales of recently-rated vehicle models.

Volvo dealers were interviewed following the inaugural release of small overlap crash test ratings with midsize luxury vehicles on August 14, 2012, in which the Volvo S60 was one of two of the 11 vehicles tested to earn the top rating of good. Suburu and Jeep dealers were interviewed following the May 16, 2013 release of small overlap crash test ratings of 13 small SUVs. The Suburu Forester was the only vehicle rated good in this round of small overlap crash testing and the first vehicle tested by IIHS in the small overlap configuration with top ratings in all aspects of the test. The Jeep Patriot was one of five vehicles rated poor. Press coverage of the test release tended to highlight the Subaru Forester and Jeep Patriot as examples of good and poor performers, respectively.

A final set of interviews with Volvo, Cadillac, Subaru, Ford, and Hyundai dealers was conducted following the September 27, 2013 inaugural release of front crash prevention ratings of midsize cars and SUVs. The Cadillac ATS and SRX equipped with Forward Collision Alert and Automatic Collision Preparation, the Subaru Legacy and Outback equipped with EyeSight, and the Volvo S60 and XC60 equipped with City Safety and Collision Warning with Full Auto Brake and Pedestrian Detection were six of the seven vehicles rated superior. The Volvo S60 and XC60 equipped only with City Safety, which brakes autonomously at low speeds and was standard equipment on these models, were two of the eight vehicles rated advanced. The Cadillac ATS and SRX equipped with Forward Collision Alert only, which warns of an imminent forward collision but does not include autobrake, and the Ford Edge, Explorer, Flex, and Fusion equipped with Collision Warning with Brake Support were six of the 28 vehicles that earned a basic rating. Hyundai had no models that were rated for front crash prevention in September 2013 and sold few vehicles with front crash prevention systems at the time.

METHODS

Telephone interviews were conducted by OpinionAmerica Group (Cedar Knolls, NJ), a professional survey organization. Phone numbers were obtained for dealerships from publicly available directories. Following the August 14, 2012 and May 16, 2013 small overlap ratings releases, interviews were attempted with all U.S. Volvo dealerships during August 28-September 6, 2012, and with all U.S. Subaru dealerships and a sample of the more than 2,200 U.S. Jeep dealerships during June 17-July 16, 2013. Of the 310 Volvo dealerships called with working phone numbers, interviews were completed with 206 (66%) and 2 (1%) refused. Subaru and Jeep dealerships were

called until 275 interviews were completed with each. Thus, among dealerships with working phone numbers, 47% of the 589 Subaru dealerships called completed interviews, 20 (3%) refused, and 4 (1%) began but did not complete the survey, and 28% of the 982 Jeep dealerships called completed interviews, 116 (12%) refused, and 6 (1%) began but did not complete the survey.

Following the September 27, 2013 announcement of front crash prevention ratings, interviews were attempted during October 28-December 3, 2013 with all U.S. Subaru, Volvo, Cadillac, and Hyundai dealerships, and a sample of the more than 3,100 U.S. Ford dealerships, with the goal of completing as many interviews as possible with Volvo dealers and 275 interviews with each of the remaining automakers. Among dealers with working phone numbers, 275 (48%) of the 572 Subaru dealers called completed interviews, and 59 (10%) refused; 176 (60%) of the 295 Volvo dealers called completed interviews, and 21 (7%) refused; 275 (26%) of the 1,080 Cadillac dealers called completed interviews, 268 (25%) refused, and 1 (<1%) began but did not complete the survey; 275 (35%) of the 792 Ford dealers called completed interviews, 74 (9%) refused, and 11 (1%) began but did not complete the survey; 275 (32%) of the 851 Hyundai dealers called completed interviews, and 125 (15%) refused. In all surveys, dealers that were called and did not refuse or begin the survey typically asked to be called back later or did not answer.

Interviewers asked to speak with the dealership's sales manager or with the general manager or owner if the sales manager was unavailable. Interviews were most often completed with sales managers (72% of interviews completed, ranging from 67%-80% among automakers). Surveys lasted about 5 minutes.

RESULTS

Surveys Following Small Overlap Crash Test Rating Releases

Dealers were asked if there was a change in the number of people who had contacted or visited their dealerships since the mid-August 2012 (Volvo) or mid-May 2013 (Subaru and Jeep) release of small overlap crash test ratings because they were interested in purchasing a Volvo S60, Subaru Forester, or Jeep Patriot, and if more, fewer, or the same proportion of customers who had contacted the dealership since the release had mentioned the safety performance of Volvo, Subaru, or Jeep as a reason for considering the brand. Larger percentages of Subaru (75%) and Volvo (49%) dealers than Jeep (12%) dealers reported an increase in calls and visits from customers interested in purchasing the tested vehicle (see Table 1). Subaru and Volvo dealers were likewise more likely to report that more customers had mentioned the safety performance of the automaker as a reason for considering it (55%-61% vs. 8%; see Table 1).

Table 1.
Customer interest in Volvo, Subaru, and Jeep vehicles and mentions of automakers' safety and crash test performance since announcement of IIHS small overlap crash test results (percent).

		Volvo (N=206)	Subaru (N=275)	Jeep (N=275)
Change in number of people who contacted or visited dealership because they are considering purchasing a Volvo S60, Subaru Forester, or Jeep Patriot	More	49	75	12
	Same	50	24	86
	Less	1	1	2
	Don't know/Refused	0	1	0
Change in number of customers who mentioned safety performance of automaker as reason for considering brand	More	55	61	8
	Same	44	35	87
	Less	<1	1	4
	Don't know/Refused	<1	3	1
Any customers mentioned automaker's performance in recent crash tests as reason for considering brand	Yes	68	77	12
	No	30	22	88
	Don't know/Refused	2	1	1

More than two-thirds of Volvo and Subaru dealers reported that since the release at least some of their customers had mentioned performance in recent crash tests as a reason they were considering the automaker, compared with 12% of Jeep dealers (see Table 1). When Jeep dealers were asked if any potential customer since mid-May had mentioned Jeep's performance in recent crash tests as a reason why they were having second thoughts about buying a Jeep, 14 dealers (5%) said yes.

Volvo dealers were asked about the dealership's sales of the Volvo S60, and of all Volvo models, for four weeks in 2012: July 29-August 4 (two weeks before the release), August 5-11 (the week before the release), August 12-18 (the week during the release), and August 19-25 (the week after the release). Similarly, Subaru and Jeep dealers were asked about sales of the Subaru Forester or Jeep Patriot, and of all Subaru or Jeep models, for three weeks in 2013: May 5-11 (the week before the release), May 12-18 (the week during the release), and May 19-25 (the week after the release).

Sales numbers for all models and the rated model in each of the four weeks were provided by 156 Volvo dealers (78%), and in each of the three weeks by 261 Subaru dealers (95%) and 269 Jeep dealers (98%). Two Volvo dealers were unable to provide sales data for the period two weeks before the release but did provide data for the subsequent weeks. Response rates for these questions improved in the survey of Subaru and Jeep dealers because interviewers encouraged dealer representatives to look up sales numbers if they did not have them readily available, which was not done in the prior survey of Volvo dealers.

Changes in total sales were examined from the week before the release to the week after the release among dealers that reported data for all weeks (see Table 2). Volvo dealers reported a much larger increase in total sales of the S60 model (41%) than of all Volvo models (18%), and Subaru dealers reported a slightly larger increase in Forester sales (14%) compared with sales of all Subaru models (11%). Jeep dealers reported a small decrease in sales of the Patriot model (2%) and a small increase in total sales for all Jeep models (<1%).

Table 2.
Sales of S60, Forester, Patriot, and all Volvo, Subaru, and Jeep models two weeks before and the week before, during, and after the release of IIHS small overlap test results, among dealers reporting for all weeks.

		Two weeks before	Week before	Week of	Week after	Percent change, week before to week after
		Jul 29-Aug 4, 2012	Aug 5-11, 2012	Aug 12-18, 2012	Aug 19-15, 2012	
Volvo	Volvo S60	317	261	329	369	41
(N=156)	All Volvo models	1,046	798	822	944	18
			May 5-11, 2013	May 12-18, 2013	May 19-25, 2013	
Subaru	Subaru Forester	—	1,243	1,203	1,422	14
(N=261)	All Subaru models	—	3,970	3,795	4,397	11
Jeep	Jeep Patriot	—	426	398	419	-2
(N=269)	All Jeep models	—	2,314	2,206	2,325	<1

At the end of the survey, dealers were asked if they knew that the S60 or Forester model had earned a good rating or that the Patriot had earned a poor rating in a recent IIHS small overlap crash test. Nearly all Volvo (94%) and Subaru (93%) dealers were aware of the performance of the S60 and Forester, respectively, prior to the survey, but fewer Jeep (38%) dealers were aware of the Patriot's performance.

Surveys Following Front Crash Prevention Rating Release

Subaru, Volvo, Cadillac, and Ford dealers were asked a series of questions regarding customer interest in vehicles with front crash prevention systems since the late September 2013 inaugural release of IIHS front crash prevention

ratings. Subaru, Volvo, and Cadillac dealers were asked about interest in vehicles with systems rated superior (Subaru's EyeSight system, Volvo's City Safety and Collision Warning with Full Auto Brake and Pedestrian Detection systems, and Cadillac's Forward Collision Alert and Automatic Collision Preparation systems), and Ford dealers were asked about vehicles with a system that earned a basic rating (Collision Warning with Brake Support). The full names of the systems were used in questions to dealers.

When asked if there was a change in the number of people who had contacted or visited their dealerships since late September because they were interested in purchasing a vehicle with front crash prevention, between 25% and 47% of dealers of the automakers with systems rated superior and 10% of Ford dealers reported an increase in interest among consumers (see Table 3). Sixty percent of Subaru dealers, 49% of Volvo dealers, 31% of Cadillac dealers, and 20% of Ford dealers reported that at least some customers interested in purchasing the vehicles with rated systems since late September had mentioned that they had seen the system included in safety ratings (see Table 3).

Table 3.
Customer interest in Subaru, Volvo, and Cadillac vehicles with front crash prevention systems rated superior and Ford models with front crash prevention systems rated basic, and mentions of safety ratings and autobrake since release of IIHS front crash prevention ratings (percent).

		Subaru (N=275)	Volvo (N=176)	Cadillac (N=275)	Ford (N=275)
Change in number of people who contacted or visited dealership because they are considering purchasing a model with front crash prevention system rated superior (Subaru, Volvo, Cadillac) or basic (Ford)	More	47	25	33	10
	Same	50	69	58	82
	Less	4	5	8	7
	Don't know/Refused	0	1	1	1
Any customer interested in purchasing vehicle with system rated superior (Subaru, Volvo, Cadillac) or basic (Ford) mentioned seeing system included in safety ratings	Yes	60	49	31	20
	No	39	50	69	79
	Don't know/Refused	1	1	0	1
Any customer interested in vehicle with system rated superior mentioned system's autonomous braking as reason for considering system	Yes	57	49	37	—
	No	41	49	63	—
	Don't know/Refused	1	2	<1	—

Dealer representatives of Subaru, Volvo, and Cadillac, which offered front crash prevention systems with autobrake, were asked if customers interested in purchasing the rated vehicles with front crash prevention systems had mentioned the system's autonomous braking as a reason they were interested in purchasing them. Between 37% and 57% of dealers of each automaker reported that since late September at least some customers had mentioned autobrake as a reason for their interest (see Table 3). Among dealers reporting that customers mentioned autobrake, 58% of Subaru dealers, 51% of Volvo dealers, and 56% of Cadillac dealers said more customers than usual had mentioned autobrake since the release.

Dealer representatives of Ford, which did not offer a front crash prevention system with autonomous braking, were asked if customers interested in purchasing a Ford with front crash prevention had asked since late September if Ford's system brakes autonomously (not in table). About a quarter (23%) reported that at least some customers asked about autobrake, and among these dealers, 32% said that more customers than usual had asked about autobrake.

Dealer representatives from Hyundai, which sold front crash prevention on a limited proportion of their vehicles, were asked if any customers had questioned if Hyundai offered forward collision warning since late September. Fourteen percent reported that customers had asked about forward collision warning.

Sales figures were obtained for IIHS-rated vehicles with front crash prevention systems and for all vehicles sold by surveyed dealers during the week before (September 15-21, 2013), during (September 22-28, 2013), and after (September 29-October 5, 2013) the ratings release. The dealers were asked about sales of rated vehicles; Subaru offered a system rated superior, Volvo offered vehicles with systems rated superior and advanced, Cadillac offered vehicles with systems rated superior and basic, and Ford offered a system rated basic. The names of the packages that included the systems were used if package names differed from system names. A total of 269 (98%) Subaru, 168 (95%) Volvo, 257 (93%) Cadillac, 271 (99%) Ford, and 271 (99%) Hyundai dealers reported sales figures for all weeks for all vehicles and, if applicable, the rated vehicles. Sales reported by automakers with rated front crash prevention systems were compared with Hyundai sales.

Total sales and sales of rated vehicles declined for all automakers from the week before the ratings release to the week after (see Table 4). However, the combined sales of Subaru, Volvo, Cadillac, and Ford models with rated systems declined 41% less than sales of Hyundai models, and the combined sales of all models from these automakers declined 6% less than sales of Hyundai models. Sales of models with each rated system declined less

Table 4.
Sales of all Hyundai, Subaru, Volvo, Cadillac, and Ford models, and sales of Subaru, Volvo, Cadillac, and Ford models with IIHS-rated front crash prevention systems the week before, during, and after the release of IIHS front crash prevention ratings, among dealers reporting for all weeks.

		Week before Sept 15-21, 2013	Week of Sept 22-28, 2013	Week after Sept 29-Oct 5, 2013	Percent change, week before to week after
Hyundai (N=271)	All Hyundai models	5,604	4,633	3,900	-30
Subaru (N=269)	MY 2013-14 Legacy and Outback with EyeSight (superior)	579	458	463	-20
	All Subaru models	4,670	4,194	3,669	-21
Volvo (N=168)	MY 2013-14 S60 and XC60 with Technology Package and City Safety (superior)	155	106	110	-29
	MY 2013-14 S60 and XC60 with City Safety and without Technology package (advanced)	696	619	598	-14
	All Volvo models	1,039	882	810	-22
Cadillac (N=257)	MY 2013-14 ATS and SRX with Driver Assist and Driver Awareness packages (superior)	525	457	439	-16
	MY 2013-14 ATS and SRX with Driver Awareness package and without Driver Assist package (basic)	412	380	339	-18
	All Cadillac models	1,323	1,116	968	-27
Ford (N=271)	MY 2013- 14 Edge, Explorer, Flex, and Fusion models with Adaptive Cruise Control and Collision Warning package (basic)	781	659	636	-19
	All Ford models	6,228	4,576	4,005	-36
Total Subaru, Volvo, Cadillac, and Ford models with rated front crash prevention systems		3,148	2,679	2,585	-18
All Subaru, Volvo, Cadillac, and Ford models		13,260	10,768	9,452	-29

than sales of Hyundai models, and total sales for each automaker offering vehicles with rated systems except Ford declined less than total Hyundai sales. There were no consistent differences among automakers in sales when comparing vehicles rated superior, advanced, and basic.

Because a lack of in-stock vehicles with systems could inhibit sales, dealers were asked if they had vehicles in stock with the rated systems at the time of the interview. More than 80% of dealers had vehicles with each optional system in stock, and nearly all (97%) Volvo dealers reported having S60 or XC60 models with the standard City Safety system in stock. It is unknown if dealers maintained the same stock levels in the weeks immediately surrounding the ratings release; historical stock was not assessed.

Dealers were told at the end of the survey that IIHS released front crash prevention ratings in late September and, if applicable, were informed how their systems were rated. Most Subaru (90%) and Volvo (85%) dealers, more than half of Cadillac (58%) dealers, and about a third of Ford (31%) and Hyundai (32%) dealers were aware of the ratings prior to the survey.

DISCUSSION

This study examined consumer interest in and sales reported by dealers of top- and poorly-rated vehicles in IIHS's small overlap crash test and of vehicles with and without front crash prevention systems rated by IIHS. A good rating in the small overlap crash test was associated with increased sales of the Volvo S60 and Subaru Forester models from the week before the ratings were released to the week after. These increases were larger than the rise in sales of all Volvo and Subaru models during this time, while sales of the poorly-rated Jeep Patriot remained flat. About half to three-quarters of Volvo and Subaru dealers also reported that customers mentioned seeing the vehicles included in crash tests, and that more customers were interested in purchasing the top-rated vehicles and mentioned the brand's safety performance as a reason they were considering them. These findings are consistent with prior research showing that consumers value safety when choosing vehicles [1-6] and demonstrate that this preference for safety extends to sales of specific vehicle models whose safety had received recent media attention.

Changes in consumer behavior following the inaugural release of IIHS front crash prevention ratings are less clear. Results indicated that some customers mentioned seeing systems included in safety ratings and some dealers reported increases in customer interest. However, reports varied by automaker and positive effects on sales were not as apparent as with the good ratings in the small overlap crash test. Sales declined for all vehicles examined from the week before the front crash prevention rating release to the week after. Sales trends likely reflected in part industry-wide factors, given that sales declined for all automakers surveyed, although it is unknown what such factors might have been. Thus, it is promising that declines were smaller among models with rated front crash prevention systems than among all vehicles and among Hyundai models, which sold few vehicles with front crash prevention at the time and did not offer vehicles with rated systems.

Consumer response to front crash prevention ratings may have been less positive than consumer response to small overlap crash test ratings because the public is less familiar with collision avoidance technologies than with crash tests. IIHS and the National Highway Traffic Safety Administration have been conducting crash tests in the United States since 1995 and the late 1970s, respectively. In comparison, front crash prevention is relatively new. A survey of Canadians during 2011-12 [7] found that only 24% were aware of forward collision warning.

Some limitations should be noted. Response rates were higher among automakers with top-rated vehicles, particularly among Volvo and Subaru dealers, than among other automakers. Volvo and Subaru dealers were also much more likely than other dealers to have known how their vehicles rated in IIHS tests. Dealers' enthusiasm to participate may have influenced their responses to questions on perceived consumer interest, and because of this limitation, it is encouraging that sales trends following small overlap crash test ratings corroborated subjective

judgments. Safety-conscious consumers may be attracted to particular automakers, which could also affect how potential customers of different automakers respond to safety ratings.

The Jeep Wrangler two-door model's marginal rating in the small overlap test was announced along with the ratings of the Subaru Forester and Jeep Patriot. Consumers' opinions of Jeep may have been affected by news reports regarding the performance of both the Patriot and Wrangler models. Finally, changes in vehicle sales were compared only between two weeks. Sales fluctuate week-to-week, and it is unknown if changes in sales persisted.

CONCLUSIONS

The goals of IIHS's vehicle ratings programs are to inform the public about vehicle safety and to encourage automakers to improve vehicle designs to enhance safety. Since IIHS introduced its ratings programs [8], automakers continue to quickly modify vehicle designs to improve crashworthiness in response to safety ratings, and this has led to safer vehicles. For instance, virtually all new vehicles are now rated good in IIHS's moderate overlap frontal crash test, and drivers of vehicles with good ratings in this test have a lower risk of dying in a head-on collision than drivers of poorly rated vehicles [9].

Automakers also have improved the performance of their vehicles in the small overlap frontal crash test and added front crash prevention systems since the new ratings were introduced. Among 2012 vehicle models that underwent the small overlap test, 28% received the top two ratings of good or acceptable; among 2015 models, 64% had received good or acceptable ratings as of February 2015. Only 20 2013 model year vehicles had front crash prevention systems rated advanced or superior, compared with 63 2015 model year vehicles as of February 2015. Both of these ratings systems are now incorporated into IIHS's *TOP SAFETY PICK* and *TOP SAFETY PICK+* awards. The current evidence demonstrates that improving vehicle designs to boost safety ratings benefits not only consumers with safer vehicles but also automakers with increased sales.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Johannson-Stenman O, Martinsson P. 2006. Honestly, why are you driving a BMW? *Journal of Economic Behavior & Organization* 60:129-46.

[2] Kaul V, Singh S, Rajagopalan K, Coury M. 2010. Consumer attitudes and perceptions about safety and their preferences and willingness to pay for safety. Report No. 2010-02-2336. Warrendale, PA: SAE International.

[3] Market & Opinion Research International. 2005. 10th anniversary consumer survey for Euro NCAP. London, England.

[4] McCartt AT, Wells JK. 2010. Consumer survey about vehicle choice. Arlington, VA: Insurance Institute for Highway Safety.

[5] Vrkljan BH, Anaby D. 2011. What vehicle features are considered important when buying an automobile? An examination of driver preferences by age and gender. *Journal of Safety Research* 42:61-5.

[6] Koppel S, Charlton J, Fildes B, Fitzharris M. 2008. How important is vehicle safety in the new vehicle purchase process? *Accident Analysis & Prevention* 40:994-1004.

[7] Robertson RD, Vanlaar WGM, Marcoux KD, McAteer HJ. 2012. Vehicle safety features: knowledge, perceptions, and driving habits. Ottawa, Ontario: Traffic Injury Research Foundation.

[8] Highway Loss Data Institute. 2013. IIHS crashworthiness evaluation programs and the U.S. vehicle fleet. *Loss Bulletin 30(7).* Arlington, VA.

[9] Farmer, C.M. 2005. Relationships of frontal offset crash test results to real-world driver fatality rates. *Traffic Injury Prevention* 6:31-37.

IMPROVING VEHICLE SAFETY IN AUSTRALIA AND NEW ZEALAND: THE ROLE OF ANCAP

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ABSTRACT

The Australasian New Car Assessment Program (ANCAP) has had a significant impact on the Australian and New Zealand motor vehicle landscape over the past 20 years through its independent, non-regulatory, consumer-driven program. Five star cars are now available in all vehicle categories; the majority of manufacturers now approach ANCAP to obtain a rating prior to launch to leverage sales; and ANCAP assessments are now seen as the de facto standard, taking the place of regulation. Since 2011 ANCAP has been increasing the stringency of its requirements for each star rating level annually. In future years ANCAP will continue to raise the bar, updating and broadening its suite of physical crash tests and introducing performance testing of safety assist technologies (SAT). These advancements will see consumers provided with even safer vehicles, and in time, perhaps even cars that will not be able to crash at all.

NCAPs drive vehicle safety improvements through a non-regulatory approach. This paper examines the effectiveness of the Australasian NCAP, its achievements and its future direction.

INTRODUCTION

The Australasian New Car Assessment Program (ANCAP) exists to provide consumers with independent, clear and concise vehicle safety information. The aim is to reduce death and injury on our roads and encourage manufacturers to supply - and consumers to demand and purchase - the safest vehicles. This is achieved through the communication and promotion of vehicle safety ratings. ANCAP uses a five star rating system (five stars being the highest rating) to communicate comparative levels of vehicle safety. While physical crash testing has dominated the program over time, advanced technology is becoming increasingly important. Historically it has been relatively simple for consumers to understand the apparent difference in safety between cars. As the photographs below illustrate, the differences were stark.

Then

Now

This is not the case today, where differences between cars may be substantial but not immediately discernible to consumers. Convincing consumers of the merits of safety technology is a huge challenge for ANCAP.

DISCUSSION

Consumer Awareness

Since the establishment of ANCAP in 1992, regular market research has been undertaken to track consumer awareness of the ANCAP brand, and also to monitor consumer uptake of the safer vehicles message and in turn, the purchase of safer cars.

Figure 1 shows the increase in consumer awareness of the ANCAP brand (both name and logo) across Australian and New Zealand new car buyers [1].

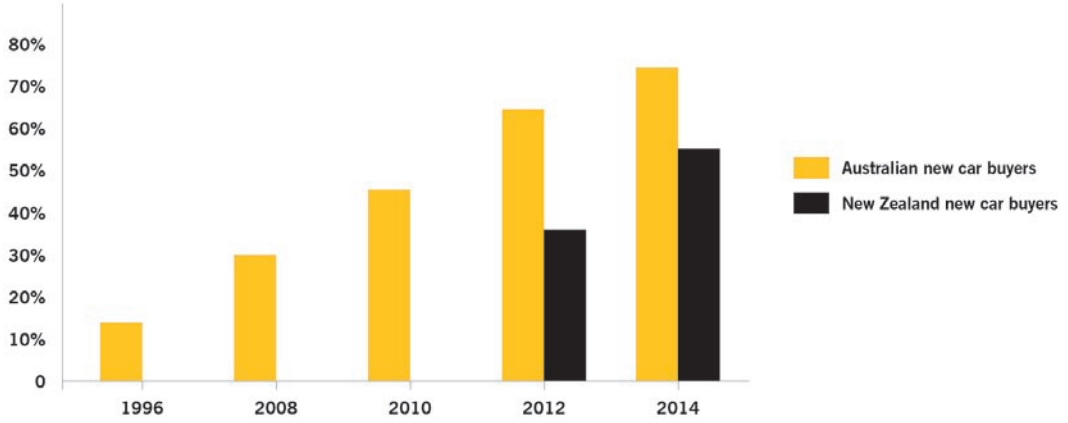

Figure 1. Awareness of ANCAP amongst new car buyers in Australia & New Zealand.

2014 results reveal that 74% of Australian new car buyers were aware of the ANCAP brand - an increase of 15% over 2012, and 60% more than 2010. Brand awareness amongst the New Zealand new car market was slightly lower at 54% in 2014, although showing significant growth since the first survey in 2012 (36%).

In order to reach these high levels of awareness ANCAP had to do two critical things. First, it had to establish itself as a professional organisation of integrity, with a strong focus on accuracy and reliability and demonstrated expertise in a complex technical field. Second, it had to convince manufacturers and consumers that this was indeed the case.

On reflection, it probably took the best part of a decade before ANCAP had made headway on the first critical point. There were many reasons for this including the fact that independent crash testing was a rather new and immature field (other than in the USA) and there was a belief in the community that if governments approved the sale of cars then *ipso facto* they must be safe. Early crash test results revealed the imprudence of this belief. Consumers were presented with the stark reality that by and large, cars were not particularly safe. Manufacturers were presented with a significant challenge in both a technical design and an ethical obligation sense. This challenge has been accepted.

As well as publishing test results, ANCAP undertook a range of marketing activities to explain and demonstrate its professional expertise and integrity of its processes. These included for example, test laboratory visits, consumer-focussed publications, greater interaction with the media, increased public advocacy for safety and closer ties with governments.

In relation to pursuing the second critical point, there were two significant events that occurred during the 2000s. The first was the awarding in 2001 of the first five star ANCAP safety rating – this made both consumers and manufacturers take notice of safety. The second was the awarding in 2008 of the first five star ANCAP safety rating for an Australian-built car. This resulted in a prominent advertising campaign during the 2008 Olympic Games where, for the very first time, a major local manufacturer extolled the benefits of an ANCAP rating to consumers.

Other manufacturers followed suit and what started as a trickle of five star ratings and associated marketing turned into an avalanche. It was clear that safety was becoming a major factor in selling cars and this was borne out in ANCAP's market research. In earlier research, safety had rated fourth or fifth in priority behind price, car type and performance.

Figure 2 shows that in 2014 Australian new car buyers ranked safety as a top priority when making purchasing decisions [1].

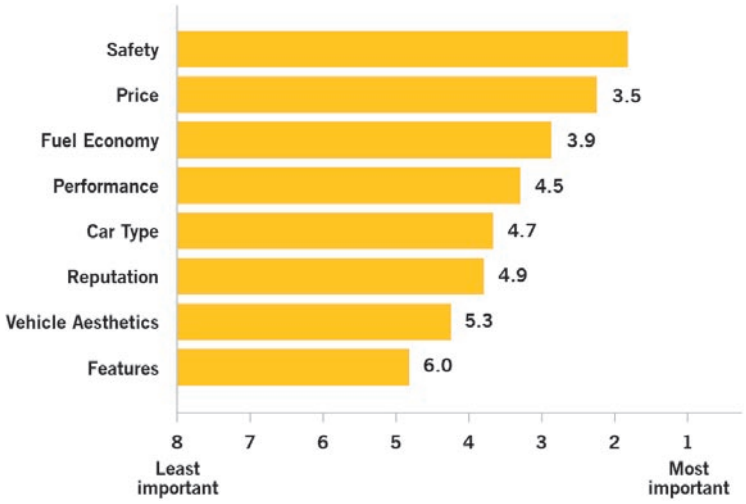

Figure 2. Importance of Vehicle Attributes to New Car Buyers, 2014.

Market Penetration

With awareness of ANCAP in Australia now high and growing quickly in New Zealand, ANCAP's influence on consumer purchasing was also apparent in the sale of five star rated cars.

Figure 3 reveals the portion of new cars sold in Australia in 2014 holding a five star ANCAP safety rating [2].

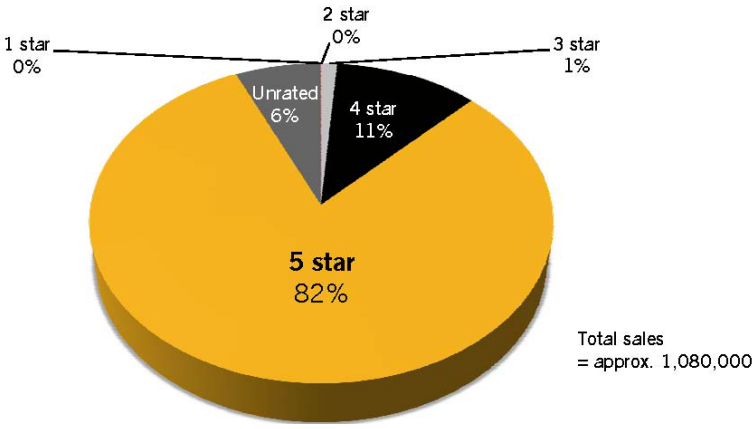

Figure 3. 2014 Australian new motor vehicle (passenger, SUV & LCV) sales by ANCAP safety rating.

In less than a decade, the penetration of five star cars in the Australian market has grown remarkably. In 2014, 82% of all new cars sold were models which held a five star ANCAP safety rating. In the relatively small Australian market this amounts to nearly 900,000 cars. A further 11% held a four star rating (~120,000 cars). Less than 2% (~20,000 cars) had a rating lower than four star, with just 6% (~65,000 cars) being models without a rating.

In New Zealand, 88% of all new *passenger* cars sold in 2014 held a five star ANCAP safety rating [3]. In both countries there are now numerous five star models available in all vehicle categories, providing a range of choices across all price points.

ANCAP's influence on five star vehicle sales can also be attributed to five star fleet purchasing policies implemented by governments and a range of private, domestic and multi-national organisations.

Positive Outcomes

With all the excitement about the prominence of ANCAP and the acceptance of safety ratings by consumers and manufacturers alike, it is easy to overlook an assessment of the outcomes of safer cars. Figure 4 sets out the reduction in fatalities on Australian roads over the last decade [4]. In that time there has been a 29% reduction in fatalities.

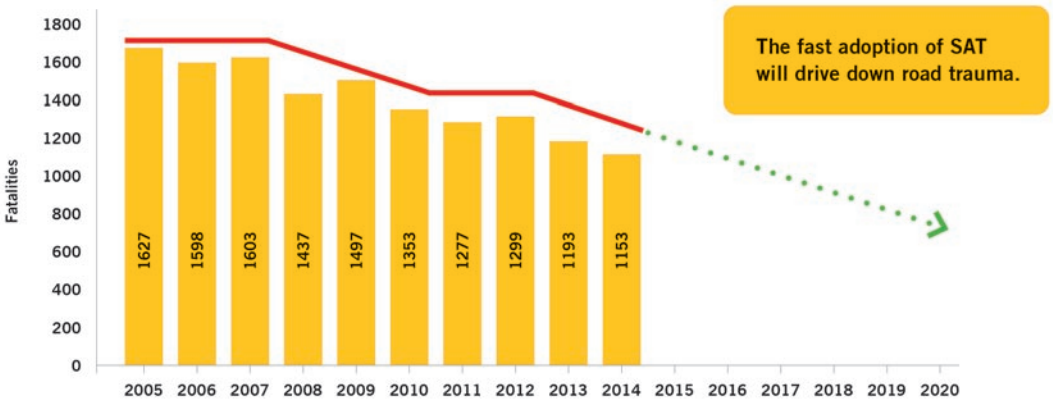

Figure 4. Australian Road Fatalities 2005-2014.

Clearly there are many factors that contribute to the reduction in fatalities, but what is also clear is that newer, safer cars play a very significant role. Figure 5 shows a snapshot of passenger vehicle fatalities and passenger vehicle registration by year of manufacture. It shows that older cars, while a smaller part of the fleet, account for a higher number of fatalities: the reverse is true for newer cars [5].

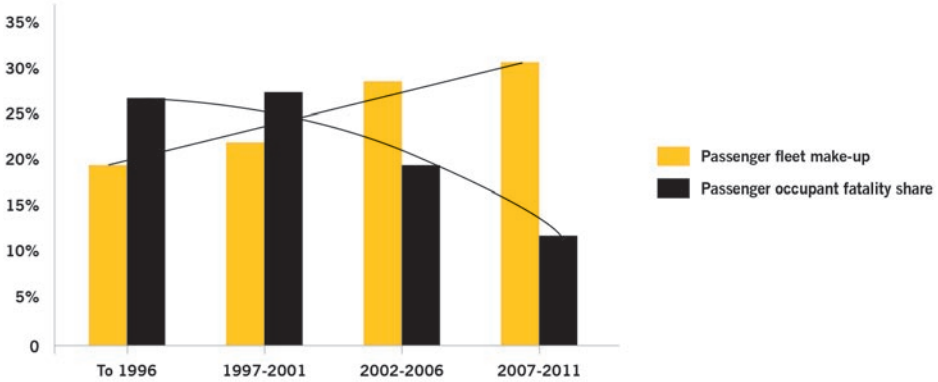

Figure 5. Passenger Fleet: Share of Registration vs. Share of Occupant Fatalities 2011.

Autonomous Emergency Braking

Since 2011, ANCAP has introduced stepped increases to the requirements vehicles must meet in order to achieve each of its five rating levels. These increases relate not only to physical crash test performance but also to the inclusion of safety assist technology (SAT) [6]. From 2015, ANCAP has taken another important step to further enhance vehicle safety, with a new focus on SAT and the substantial impact it will have on reducing road trauma. This will be achieved through ANCAP's alignment with Euro NCAP and the move to a more sophisticated test and assessment program encompassing performance assessments of active, life-saving SAT [7]. From 2018 ANCAP and Euro NCAP testing and assessment regimes will be effectively aligned.

In spite of the positive outcomes of recent road safety initiatives, over the last fifteen years Australia has slipped from eleventh to sixteenth place in the world in terms of road deaths per 100,000 population. More must be done to see this decline reversed and SAT has a huge role to play in achieving this.

Today, autonomous emergency braking (AEB) has already shown significant benefits in reducing the number of crashes. Early figures showed a 27% reduction in Europe [8] and 14% in US [9]. Recent Swedish research reveals AEB has reduced the risk of real world rear-end crashes in metropolitan areas by 54-57% and in all areas

by 35-41% [10]. These figures are largely supported by other, as yet unpublished, research (funded in part by ANCAP).

The central issue now is how we encourage consumers to demand, and manufacturers to supply, this technology. If left to the market alone it may be many years before the technology becomes available in all new cars and perhaps decades before it becomes ubiquitous in the fleet. Regulating the technology would likely lead to a similar outcome given the time it takes to develop and implement. The only practical way to ensure that this technology has an accelerated introduction into the market is for consumers, road safety practitioners and fleets to demand it. This puts a particular onus on ANCAP and other programs to pursue this with vigour.

Autonomous Technology and the Consumer

The idea of autonomous cars may well have its roots in the twentieth century development of the automatic transmission and other similar devices. Over time there have been many incremental advancements, but none is more exciting or arouses more fear than the prospect of the autonomous car. The move to autonomy has accelerated rapidly in the last decade and shows no signs of slowing. While it seems inevitable that at some time in the future all cars will operate this way, there are some challenges to face before we arrive at that future time.

The world is full of autonomous devices and machinery that once required specialised training and human control and intervention. Trains, ships, trucks, aeroplanes are all good examples and while most are happy to get on an aeroplane and fly thousands of kilometres at speeds approaching the sound barrier, there is something about owning and driving a car that on occasion provokes an irrational response to change, notwithstanding that the risk of death or serious injury is much higher in a car than in these other forms of transport.

The inevitable progression of advanced technology presents a new set of challenges for ANCAP in maintaining consumer trust. Having been exposed to the results of physical crash testing and graphic images of cars that perform well and those that perform poorly, the consumer has been an active participant in safety because the results are evident and the benefits apparent.

This may not be the case with some of the more technically complex SAT. There are no tangible images of good and bad performance to which the consumer can relate.

Surrendering control of the car will be difficult for those already driving. Driving skills are often worn like a badge of honour, particularly among younger people and if this is threatened, resistance will be strong. However, there is light at the end of the ‘generational’ tunnel and the existence of this light will ensure that subsequent generations of drivers will embrace technology and readily accept a new and different place for the car in society.

CONCLUSIONS

ANCAP has had a significant impact on Australian and New Zealand motor vehicle safety over the past 20 years through its independent, non-regulatory, consumer-driven program. Five star rated cars are now common; manufacturers are embracing the ANCAP process by actively pursuing and promoting ratings; and consumer awareness and use of ANCAP ratings is at a record high. Accelerated introduction of life-saving technology is vital and new methods of communicating this to consumers and manufacturers will be required.

The era of autonomous technologies has commenced and consumers and NCAPs alike must acknowledge and embrace it if there is to be a further dramatic reduction in road trauma. ANCAP's future test, assessment and communications processes will therefore continue to evolve in order to ensure that consumers secure access to the safest cars, and in time, perhaps to cars that will not crash.

REFERENCES

[1] ANCAP brand tracking research, Intuitive Solutions (April 2014).

[2] ANCAP & VFACTS vehicle sales data analysis (January 2015).
SUV = sports utility vehicles, LCV = light commercial vehicles (excludes heavy vehicles).

[3] New Zealand Motor Industry Association new vehicle registration (sales) data (January 2015).

[4] BITRE Road Deaths Monthly Bulletins (January 2015).

[5] Compiled from 2012 Australian Bureau of Statistics Survey registration data & BITRE Australian Road Deaths Database (includes SUV).

[6] SAT is a generic acronym for active safety devices and systems (e.g. stability control, autonomous braking, fatigue warning, lane departure warning, adaptive headlights).

[7] ANCAP Transition to Alignment with Euro NCAP (October 2014).

[8] Euro NCAP Autonomous Emergency Braking Fitment Survey (June 2012).

[9] IIHS / HLDI News Statement: *Crash avoidance features reduce crashes, insurance claims study shows; autonomous braking and adaptive headlights yield biggest benefits* (3 July 2012).

[10] Rizzi, M., Kullgren, A., Tingvall, C. (2014). *Injury crash reduction of low-speed Autonomous Emergency Braking (AEB) on passenger cars*.

VEHICLE SAFETY TRENDS AND THE INFLUENCE OF NCAP SAFETY RATINGS

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ABSTRACT

In 1999 the Australasian New Car Assessment Program (ANCAP) aligned its test and assessment protocols with Euro NCAP and began issuing safety ratings, with a maximum rating of 5 stars. In effect, to achieve 5 stars, the vehicle needed good frontal offset crash test performance and good head protection in intrusive side impacts. The rating system awards bonus points for intelligent seat belt reminders and, recently, requires certain safety features such electronic stability control (ESC) and emergency brake assist (EBA).

The proportion of models achieving a 5-star safety rating has gradually increased from zero in 2002 to an estimated 75% of models on sale in 2014. This paper presents an analysis of trends with safety ratings and the uptake of key safety features during this period.

This paper also provides estimates of future savings due to the penetration of 5-star vehicles into the Australian vehicle fleet.

INTRODUCTION

The Australasian New Car Assessment Program has conducted consumer crash tests since the early 1990s. These tests cover passenger cars and light commercial vehicles. In 1999 ANCAP aligned its test and assessment protocols with Euro NCAP and began publishing safety ratings with a maximum rating of 5 stars. About half of ANCAP's ratings since then have been based on crash tests conducted by Euro NCAP.

Under these protocols a vehicle needed to perform exceptionally well in three crash tests: frontal offset at 64km/h (maximum 16 points), mobile barrier side impact at 50km/h (maximum 16 points) and side pole impact at 29km/h (maximum 2 points). To score the maximum 5 star rating the combined score also needed to be at least 32.5. The Renault Laguna became the first ANCAP 5-star model in 2001. In 2003 Euro NCAP introduced up to 3 bonus points for intelligent seat belt reminders (SBR). In that year the Mercedes-Benz C-Class achieved a 5-star rating by including driver and front passenger SBR.

It became evident to ANCAP that a vehicle could achieve a 5-star rating without the need for a pole test (and therefore without head-protecting side airbags - head protection technology or HPT). Therefore in 2004 it was made a 5-star requirement that, to be eligible for a 5 star rating, a vehicle must score at least one point (out of 2) in the pole test.

In 2008 ANCAP made it a 5-star requirement that a vehicle has ESC as standard. In 2011 ANCAP published its 2011-2017 Road Map which required minimum performance in pedestrian protection and whiplash protection as well as a range of safety assist technologies (SAT). For example, for a 5-star safety rating in 2013 the vehicle needed driver and front passenger SBR and EBA. In 2014 the side head protection needed to cover the 2nd row outboard seats and in 2015 any 2nd row fixed (non-removable) seats required SBR. The Road Map also requires a minimum number of additional (non-mandatory) SAT and manufacturers are able to choose from a list of more than forty SAT for this purpose.

In Australasia there is a strong demand for vehicles with a 5-star safety rating. For example many fleet buyers now set this as a purchasing requirement. This demand for 5-star vehicles, combined with the increasingly higher requirements for a 5-star rating means that ANCAP has likely accelerated the uptake of safer vehicles and key safety technologies.

This paper sets out the results of an analysis of the trends with safety ratings and the uptake of key safety features during the period 2001-2014. These trends are also projected to 2020 to provide an estimate of the

road trauma savings that can be expected from increasing use of 5-star rated vehicles.

SOURCES OF DATA

ANCAP maintains a database of safety ratings for vehicle models and the key safety features that are available for these models. The database was analysed to provide an estimate of the number of vehicle models available for sale in a particular year that were 5-star rated or not.

It took several years for ANCAP to assign star 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 and so the estimates of the uptake of safety features, and star rating are likely to be higher than the actual numbers.

Using data from the VFACTS service, an estimate was also made of the annual sales of each model. From this an estimate was made of the proportion of annual sales that were 5-star models. Note that this is not the same as the proportion of new ANCAP ratings that were 5-stars in any particular year. There are many older models that are still on sale as new vehicles and these are less likely to be 5-stars than new models to the market.

A desirable aim for safer vehicles is to increase the proportion of 5-star rated models in the total annual kilometres travelled by light passenger vehicles (vehicle kilometres travelled or VKT). Newer vehicles tend to travel higher annual kilometres than older vehicles and so data published by the Environmental Protection Agency of NSW on VKT by vehicle age for the 2008 calendar year was utilised in the analysis (EPA 2012). A key assumption is that these proportions do not change greatly in earlier or subsequent years. In other words, a 3 year old vehicle in 2008 has the same proportion (8%) of annual light passenger vehicle VKT as a 3 year old vehicle in 2001 or 2014. The VKT data is listed as an appendix.

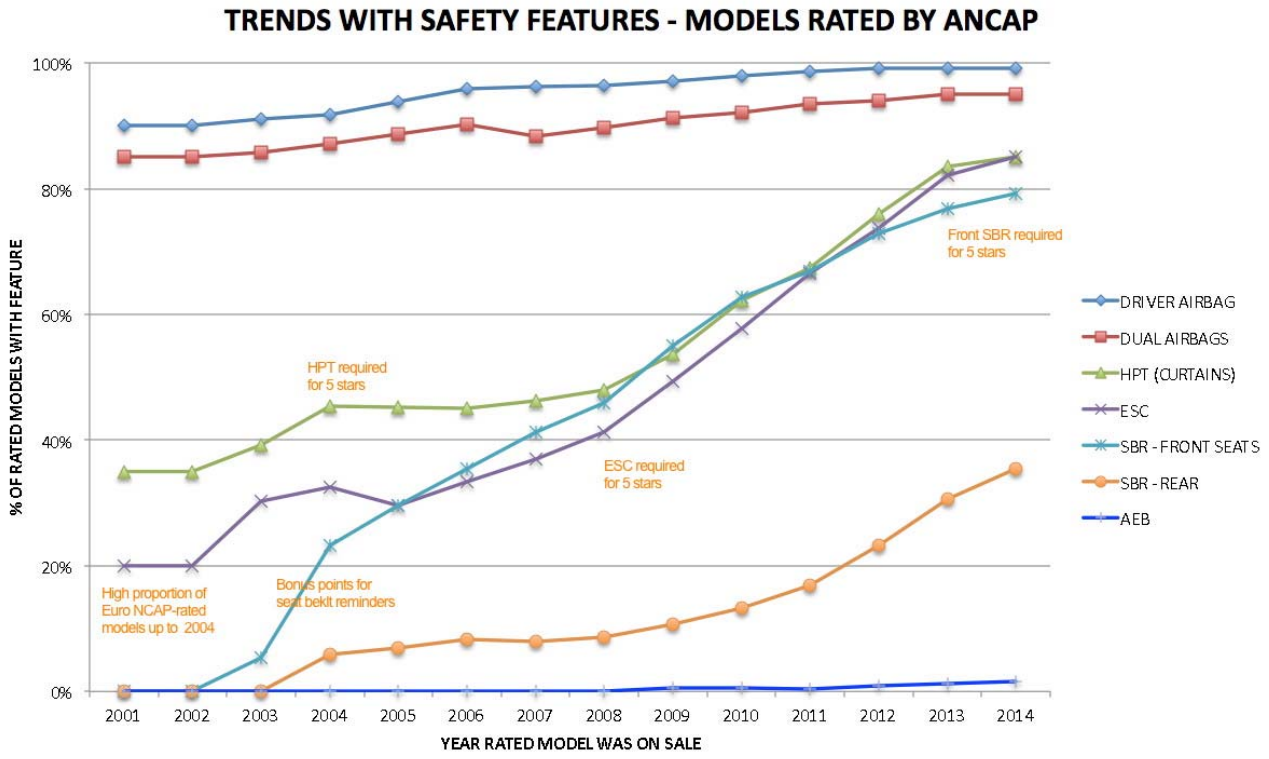
RESULTS

Figure 1 shows the uptake of key safety features of models rated by ANCAP in the period 2001 to 2014. The figure also shows milestones in ANCAP-related policy that likely had an influence on this uptake.

Table 1. Estimated uptake of safety features

Safety Feature	2001*	2007	2014
HPT	35%	46%	85%
ESC	20%	41%	85%
Front Passenger SBR	0%	46%	79%
2nd row SBR	0%	9%	35%
AEB	0%	0%	2%

* Biased towards European models



DISCUSSION - SAFETY FEATURES

Frontal airbags

By 2001 most popular cars already had frontal airbags for the driver and passenger. The 10% of models without a driver airbag in 2001 were mostly light commercial vehicles such as pickups and vans. It is likely that during the following decade ANCAP contributed to the uptake of frontal airbags on these remaining models, or their withdrawal from the market. There were no regulation changes during this period that might have influenced this trend.

Head-protecting side airbags

A new Global Technical Regulation on Pole Side Impact will be introduced under the Australian Design Rules (ADR) in the next few years. This will be the first global regulation that requires head protection in severe side impact crashes.

Since 2001 the Euro NCAP/ANCAP protocols strongly encourage head-protecting side airbags through the side pole test. About one third of the models rated by these organisations in 2001 had HPT. This improved steadily to 46% by 2007 and then uptake increased, with 85% of rated models having the technology by 2014. The demand for 5-star rated models is likely to have contributed to the improved uptake.

Electronic stability control

Subject to the over-representation of prestige European models between 2001 and 2004, there was a gradual uptake of ESC on models rated by ANCAP. Increased uptake is evident from 2008 when ANCAP made ESC a mandatory requirement for the 5-star safety rating. This was at a time when the demand for 5-star rated models increased. Other factors at this time were an industry-based voluntary code for fitting ESC and the announcement of amendments to the Australian Design Rules to require ESC on new models from November 2011.

Despite these regulatory changes there are some models being offered for sale without ESC. To address this ANCAP has made ESC mandatory for a 2-star safety rating from 2014. A vehicle without ESC cannot do better than a 1-star safety rating.

Seat belt reminders - front seats

The Australian Design Rules require a basic warning system for the driver's seat belt but there are no regulations that encourage the fitting of advanced seat belt reminders to vehicles. These devices were only available on a handful of models prior to 2003.

ANCAP and Euro NCAP introduced bonus points for seat belt reminders in 2003 and the uptake was quite dramatic from that time, improving from 20% to 80% of rated models between 2004 and 2014. The bonus points enabled many models to reach a total score sufficient for a 5-star safety rating.

ANCAP made front seat belt reminders mandatory for 5-stars from 2013 and for 4-stars from 2015.

Seat belt reminders - rear seats

Under the protocols a vehicle with seat belt reminders for all rear seats can earn a bonus point. It is apparent that this was not strong incentive for uptake of this technology, despite the protocol only requiring a warning if there was a change in state of the seat belt use (the front passenger seat requires occupant detection). By 2014 only one third of rated models had rear seat belt reminders.

To address the low uptake of rear seat belt reminders the ANCAP Road Map includes them as a mandatory 5-star requirement for 2nd row fixed (non-removable) seats from 2015. The Euro NCAP protocols also strongly encourage seat belt reminders for all seats through the Safety Assist component of the rating system.

Autonomous emergency braking

AEB is a relatively new technology that has excellent potential for reducing road trauma (Anderson 2012).

Less than 2% of the models rated by ANCAP in 2014 had AEB as standard. Several Australasian models had AEB available on higher-priced variants but not on the base variant.

The situation is different in Europe. For example about half of the models rated by Euro NCAP in 2014 earned points for AEB. Since 2013 the Euro NCAP rating system has encouraged the uptake of AEB. The ANCAP Road Map 2011-2017 includes AEB in the list of additional SAT but it is evident that stronger encouragement is needed to reach the levels of uptake seen in Europe.

From 2018 ANCAP will be aligning its protocols with Euro NCAP and this is expected to focus attention on AEB. In the meantime, through media releases and other communications strategies, ANCAP is encouraging consumers to ask for AEB. For example, ANCAP datasheets now indicate if AEB is available in Europe but is not available on any Australasian variant - a measure intended to put pressure on the Australian distributors.

Speed assist systems

The Euro NCAP Safety Assist protocol also encourages manufacturers to fit speed assist systems (Schram 2013). 85% of models rated by Euro NCAP in 2014 earned points for Speed Assist Systems (SAS).

Most of these had a manual speed assist (MSA) function, where the driver sets an upper limit to the vehicle speed. This is similar to the operation of cruise control and many recent MSA systems utilise the same driver controls as cruise control (set, cancel, resume etc).

From a safety perspective the use of MSA is preferred to cruise control because driver intervention (such as pressing the cancel button) is required in order to slow down a vehicle that is operating under cruise control. This can take several seconds. With MSA the driver simply reduces throttle to slow down and driver intervention is only necessary when the driver wishes to exceed the set speed. This is more practical for typical motorways and busy rural roads where slower moving traffic is frequently encountered but the driver wishes to not exceed a certain speed (preferably the posted speed limit) at other times. It is less complex and much less costly than adaptive cruise control, which is intended to achieve similar outcomes without driver intervention.

The other SAS function rewarded by the Euro NCAP protocols is a Speed Limit Information Function (SLIF). The driver is provided with information about the posted speed limit. This can be done through digital mapping of speed limits, through the recognition of speed limit signs or a combination of these systems. Several models rated by Euro NCAP in 2014 had digital maps or optical sign recognition.

There is good potential for SAS to reduce road trauma (Paine 2013a). The next step is Intelligent Speed Assistance (ISA) where, in effect, the SLIF and MSA are combined so that the maximum vehicle speed is automatically set according to the posted speed limit, unless the driver intervenes. The Euro NCAP SAS protocol awards additional points for ISA but, so far, no models have received these bonus points. This is expected to change as the coverage and reliability of digital mapping improves. For example, during 2014 the New South Wales government released a smartphone application which alerted drivers to speeding throughout NSW, including time-based 40km/h school zones. The government also made the data on posted speed limits available to the private sector for use in navigator applications and other uses.

The ANCAP Road Map 2011-2017 includes SAS as an additional SAT. Historical data about the uptake of SAS is not readily available and so SAS has not been included in Figure 1. However it is expected that manufacturers, fleets and consumers will give greater attention to SAS when ANCAP aligns its protocols with Euro NCAP in 2018.

Fleet purchasing policies

In 2011 the Australian government amended its fleet purchasing policy to require cars to have a 5-star ANCAP safety rating and for light commercials to have a 4-star rating.

In 2012 BHP Billiton, introduced a 5 star NCAP safety rating requirement across its worldwide vehicle fleet. This included light commercial vehicles and followed the release of the 5-star Ford Ranger pickup in late 2011. This generated substantial interest from other pickup manufactures and most popular brands are now available with 5 stars safety ratings.

PROJECTED BENEFITS OF SAFER VEHICLES

Paine (2013b) analysed data from Australasian real-world crashes to track the improvement in occupant safety as vehicle models improve in star ratings. That analysis found that the risk of serious injury to drivers of 5-star models was half of that for drivers of vehicles with the same model name when it was 3-stars or less.

That analysis is considered to be a reasonable approximation for dividing the Australian light vehicle fleet into "5-stars" and "not 5-stars" for the purpose of determining benefits for all light vehicle occupants. The following analysis therefore assumes that if all non 5-star models were replaced by 5-star models then light occupant fatalities and serious injuries would reduce by 50%. This is in the range of values from analysis of real-world crashes in Europe: a reduction of 23% (+/-8%) for serious injuries and 68% (+/-32%) for fatalities (Kullgren 2010). Furthermore, Newstead (2014) reported that a typical 2010 Australian car had 40% lower risk of serious injury to the driver than a 2001 model (based on his Fig 20). It is estimated that 56% of sales in 2010 were 5-star models and that the relative savings from these was around 30%.

It is expected that the sales of 5-star models will level out during the next 5 years. It is assumed that by 2020 95% of sales will be in 5-star models and that two-thirds of VKT will be in 5-star models.

RESULTS

Table 2. Estimated benefits from 5-star models

Parameter	2001	2007	2014	2020
5-star sales	0%	18%	86%	95%
5-star models on the market	0%	33%	75%	82%
% of fleet 5-stars	0%	4%	31%	61%
Annual VKT in 5-stars	0%	5%	34%	67%
KSI relative to 2001	100%	98%	83%	66%

The results are set out in Figure 2.

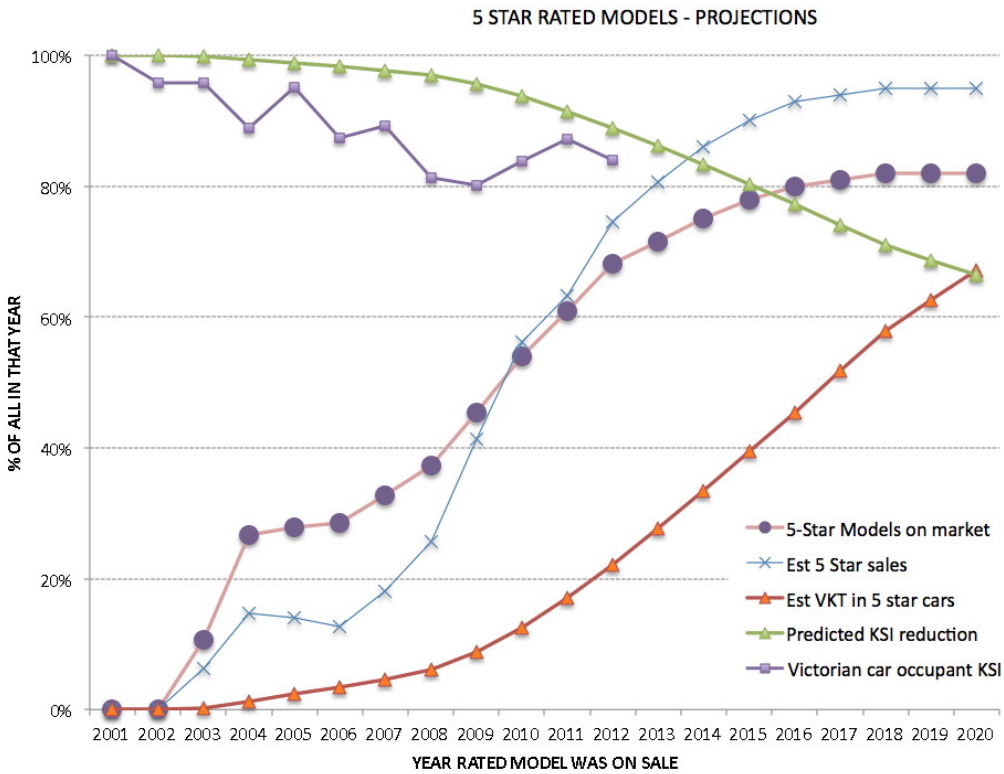


Figure 2. Trends will 5-star models and projected savings

DISCUSSION OF POTENTIAL BENEFITS

Light vehicle occupant casualties (killed and seriously injured) are likely to have dropped by 17% between 2001 and 2014 due to the uptake of 5-star rated vehicles.

There are very few sources of data about actual occupant casualties in Australia during this period. Once source is the TAC online database for Victoria for the period 2001-2012 (see appendix). These data are also shown in Figure 2. The Victorian data show that light vehicle occupant KSI reduced by 16% during this period. The estimated reduction due to VKT in 5-star vehicles in 2012 is 11%.

There were many other road-safety initiatives that contributed to the reduction in overall road crash casualties during the period studied. However an indication of the benefits of 5-star models can be obtained by applying the 2014 fleet composition to the 2001 Australian road toll. Extrapolating the TAC data for Victoria, it is estimated that there were 1200 fatalities and 17400 serious injuries to *occupants of light vehicles* in 2001(when no vehicles were 5-stars). If 34% of VKT (the 2014 estimate) had been in 5-star models during 2001 then there would have been 200 fewer fatalities and 2900 fewer serious injuries to light vehicle occupants. The societal cost savings would have been in excess of one billion dollars (based on BITRE 2009).

The forward projections are somewhat speculative but it is evident that the benefits from the increase in sales of 5-star models over the past 5 years are resulting a replacement of older models with newer, safer vehicles. It is estimated that in 2014 34% of VKT were in 5 star models and that this will double by 2020. As a result it is predicted that light vehicle occupant KSI will have reduced to 66% of the 2001 value.

LIMITATIONS

Reliable information about the availability of safety features during the study period is not available. This analysis is based on ANCAP historical data and the assumption that there is very little uptake of optional safety features. Additionally it is difficult to determine when some safety features became standard on certain models. This uncertainty will also affect the estimate of 5-star models sold.

Assumptions about VKT by age of vehicle are based on EPA estimates for 2008 and may have changed by 2014.

There is limited information about the number of serious injuries to light vehicle occupants in Australia during the study period.

CONCLUSIONS

Since 2001 ANCAP made a major contribution to the uptake of several important safety features on light vehicles. Regulation initiatives for these safety features either do not exist or lag ANCAP initiatives by five years or more.

The proportion of the light vehicle sales with a 5-star ANCAP safety rating has increased strongly from 2008. As a result older vehicles are being replaced by safer 5-star vehicles at an increasing rate. It is predicted that, by 2020, this effect will result in a saving of approximately 34% in light vehicle occupants killed and seriously injured, compared with a vehicle fleet that had the same crashworthiness as that in 2001. Societal cost savings are estimated to be more than AU$2 billion per year (that is, twice that estimated for 2014).

NCAPs are now encouraging the uptake of the latest crash avoidance technologies, such as autonomous emergency braking and improved protection for vulnerable road users struck by light vehicles. These should result in further casualty savings for a wider range of road users.

This analysis shows that NCAP programs are highly cost-effective.

REFERENCES

Anderson R, Doecke S, Searson D (2009) *Vehicle age-related crashworthiness of the South Australian passenger fleet* , Centre For Automotive Safety Research, CASR0106 April 2012

Anderson R, Doecke S, Mackenzie J , Ponte G, Paine D & Paine M (2012) Potential benefits of forward collision avoidance technology, Centre For Automotive Safety Research, CASR0106 April 2012

BITRE (2009) *Cost of Road Crashes in Australia in 2006,* Dept Infrastructure and Transport, Canberra

EPA NSW (2012) *Air Emissions Inventory for the Greater Metropolitan Region in New South Wales 2008 Calendar Year - On-Road Mobile Emissions: Results*, Technical Report 7, Environment Protection Authority of NSW, Sydney

Kullgren A., Lie A. and Tingvall C. (2010) *Comparison between Euro NCAP test results and real-world crash data*, Traffic Injury Prevention, 11:587-593, 2010

Lie A., Kullgren A. and Tingvall C (2001) *Comparison of Euro NCAP test results with Folksam car model safety ratings*, *Proceedings of 17th ESV,* Netherlands

Newstead S, Watson L and Cameron M (2014) *Vehicle safety ratings estimated from police reported crash data: 2014 update Australian and New Zealand crashes during 1987-2012,* Report 323, Monash University Accident Research Centre, Australia

Paine M., Griffiths M., Haley J and Newland C. (2009) *Injury and structural trends during 12 years of NCAP frontal offset crash tests*, Proceedings of 19th ESV, Washington

Paine D, Paine M, Wall J & Faulks I (2013a) *Development of an assessment protocol for after-market speed limit advisory devices*, Proceedings of 23rd ESV, Seoul

Paine D, Paine M, Case M, Haley J, Newland C and Worden A (2013b) *Trends with ANCAP safety ratings and real-world crash performance for vehicle models in Australia*, Proceedings of 23rd ESV, Seoul

Schram R, Williams R, van Ratingen M, Strandroth J, Lie A & Paine M (2013) *NCAP Test and Assessment Protocols for Speed Assistance Systems, a first in many ways*, Proceedings of 23rd ESV, Seoul

APPENDIX

Estimated Vehicle Kilometres Travelled by Vehicle Age in 2008 (EPA 2012).

Vehicle Age (Years)	% of light vehicle fleet	% of total annual light vehicle VKT
New	6.25%	4%
1	6.34%	8%
2	6.77%	8%
3	6.88%	8%
4	7.05%	7%
5	6.77%	7%
6	5.56%	6%
7	5.03%	6%
8	5.25%	6%
9	5.78%	6%
10	4.93%	5%
11	3.98%	5%
12	3.75%	5%
13	3.46%	5%
>13	27%	13%

Notes

These values reflect changes in the total number of vehicle sales each year, due mainly to economic issues. This is not expected to have major effect on the analysis since the contribution of any one year is relatively small.

The mean age of the Australian light vehicle fleet in 2008 was 10 years (Anderson 2009)

Victorian car occupant casualties 2001-2012

(http://www.tac.vic.gov.au/road-safety/statistics/online-crash-database)

Year	Killed or seriously injured	% of 2001
2001	4525	100%
2002	4337	96%
2003	4332	96%
2004	4025	89%
2005	4307	95%
2006	3951	87%
2007	4035	89%
2008	3677	81%
2009	3627	80%
2010	3792	84%
2011	3948	87%
2012	3799	84%

Notes

There is no adjustment for exposure in these data

Used Car Safety Ratings (Newstead 2014 Fig 20)

Risk of serious injury to driver

Vehicle type	1997-2001	2002-2006	2007-2012
Large car *	66%	53%	35%
Small car*	77%	54%	48%
Utility*	63%	50%	40%
Large car #	100%	80%	53%
Small car#	100%	70%	62%
Utility#	100%	79%%	63%
Average#	100%	76%	60%

* Relative to 1982-86

Relative to 2001

CRASHWORTHINESS TESTING OF ELECTRIC AND HYBRID VEHICLES

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Paper Number 15-0318

ABSTRACT

Electric and hybrid vehicles are increasingly being offered as a means to provide personal transportation with less negative impact on the environment and lower operational cost. While still representing a small portion of fleets in industrialized countries, the availability of these types of vehicles is growing. Electric and hybrid vehicles comprised approximately 1 percent of new vehicle sales in the United States in 2004, and by 2013 this had grown to almost 4 percent. As a result, there is considerable interest in the crash safety of these vehicles and, in particular, potential hazards unique to their electrical drive systems such as electrocution, fire, and electrolyte spillage. This paper summarizes the crash test experience of electric/hybrid vehicle from the Australasian New Car Assessment Program (ANCAP) and Insurance Institute for Highway Safety (IIHS).

Since 2004, ANCAP and IIHS have subjected 42 hybrid and electric drivetrain vehicles to a variety of crashworthiness tests including both moderate and small overlap front crashes, side crashes, and roof strength tests. Crashworthiness results are summarized with special attention paid to the risk of electrical drive system hazards, and laboratory best practice related to electric vehicle testing is described.

The crashworthiness of hybrid and electric drive vehicles is typically similar to that of vehicles with internal combustion engines. IIHS has assigned eight good ratings, three acceptable ratings, and three poor ratings in frontal crash tests (both moderate and small overlap tests); 10 good ratings and one poor rating in side crash tests; and eight good ratings and one acceptable rating in roof strength tests. To date, ANCAP has assigned one 4-star rating and two 5-star ratings to electric vehicles in its evaluation program. Neither organization observed damage to the batteries or other portions of the electrical drive systems that indicated a potential risk.

Safety precautions and inspections of the electrical systems have evolved to include post-crash checks for isolation of high voltage from the chassis, leakage of volatile gases, and physical damage of the systems. In addition, vehicles are quarantined and observed after a test to ensure hidden damage does not result in fire risk developing over time.

Ten years of crash testing electric/hybrid vehicles by ANCAP and IIHS, covering a wide range of crash conditions, indicates the variation in crashworthiness performance of hybrid/electrical drive vehicles is comparable with the variation observed with conventionally powered vehicles. Neither ANCAP nor IIHS has observed problems associated with the electrical drive systems in tests of more than 40 hybrid and electrical vehicles. This observation suggests safety designers are providing good protection of the electrical drive systems in crashes represented by federal and consumer information tests.

While vehicles with high-voltage batteries present unique challenges to laboratory safety, ANCAP and IIHS experience suggests these potential hazards can be managed. Using appropriate tools and taking extra steps to ensure isolation of the battery from other parts of the vehicle has resulted in the successful execution of electric vehicle crash tests by both organizations without injury or other dangerous incident.

INTRODUCTION

Tougher fuel economy standards have spurred automakers to make design changes to their vehicle fleets to meet new regulations. Making vehicles lighter, installing smaller engines, using alternative fuels, and manufacturing hybrid and electric vehicles are some of the strategies for increasing fuel economy.

A vehicle is considered a hybrid if it has more than one power source to propel the vehicle, typically an internal combustion engine and electric motor. An electric vehicle is equipped with one or more electric motors to propel the vehicle. Both hybrid and electric vehicles have high-voltage battery packs, often referred to as Rechargeable Electric Storage Systems (RESS).

In 1999, the Honda Insight was the only hybrid electric vehicle (HEV) available in the United States, with 17 vehicles sold. In 2000, the Toyota Prius was introduced, with more than 5,500 vehicles sold. In 2004, the Honda Civic hybrid was introduced, with sales of 13,700 units. Beginning in 2004, there have been at least two new HEV models introduced each year, with 11 introduced in 2012. A total of 47,600 HEVs were sold in the United States in 2003. By 2013, that number had grown to almost 500,000 units (Figure 1). In 2013, there were 46 HEV models available in the U.S. market [1].

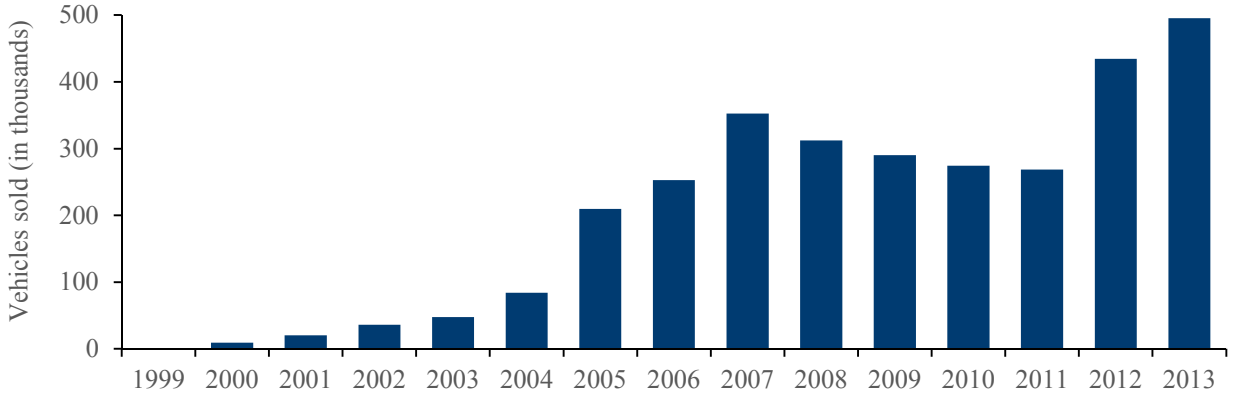

Figure 1. Hybrid and electric vehicle sales, United States.

The first mainstream plug-in electric vehicles (PEV) available in the United States were the Nissan Leaf and Chevrolet Volt, both introduced in December 2010, with sales of 19 and 326 units, respectively. Two additional PEV models were introduced in 2011, the Mitsubishi i-MiEV and Smart ED, with sales of 76 and 310 units, respectively. Nine PEVs were introduced in 2012, and six in 2013. By 2013, PEV sales totaled almost 100,000 units (Figure 2). There were 16 PEV models for sale in the United States in 2014 [1].

Sales of PEV and HEV vehicles in the United States have increased annually, from 17 vehicles in 1999 to 592,231 vehicles in 2013, approximately 3.5 percent of all passenger vehicles sold. The sales volume of electric/hybrid vehicles in Australia is smaller (Figure 3), but the same upward trend is evident [2][3][4][5][6][7][8][9][10][11][12].

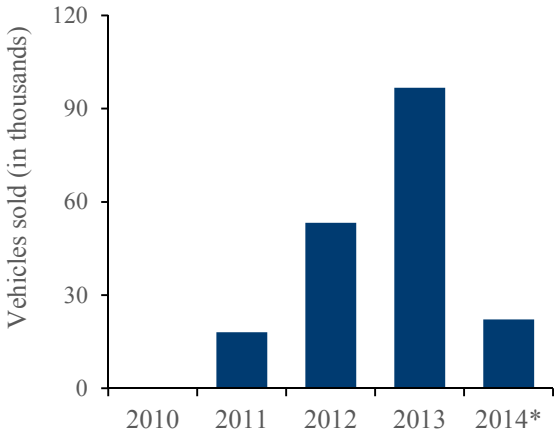

Figure 2. Plug-in electric vehicle sales, United States (*2014 sales, through first quarter).

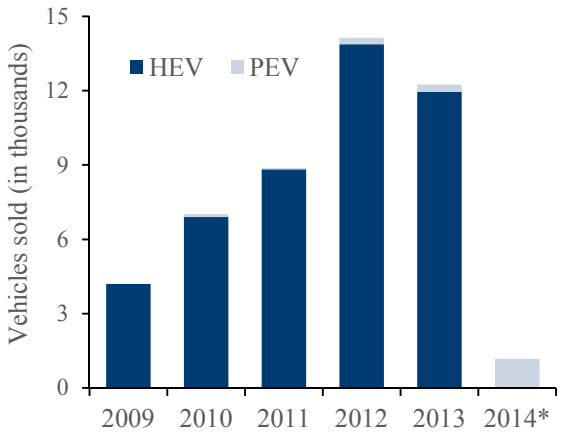

Figure 3. Plug-in electric and hybrid vehicle sales, Australia (*HEV sales not available).

Real-World Safety Concerns

Electric/hybrid vehicles have a number of safety concerns not associated with conventional vehicles including electrocution, explosion, electrolyte spillage, and/or fire. There have been numerous real-world examples of electric vehicles catching on fire after a crash and in the garages where they were being stored; in some cases, this may have been while the vehicle was being charged.

The most widely publicized fire incident involved a 2011 Chevrolet Volt after it was crash tested at MGA Research, in Burlington, Wisconsin, in June 2011. The Volt's lithium-ion battery caught on fire 3 weeks after being subjected to an 18 mi/h side pole test as part of the National Highway Traffic Safety Administration's (NHTSA) New Car Assessment Program (NCAP). The fire quickly spread to three adjacent vehicles. An extensive post-fire investigation later determined that a small amount of battery coolant penetrated the high-voltage battery case after the crash, causing the battery to short and eventually leading to a thermal runaway condition [13].

In 2012, 16 Fisker Karma electric vehicles caught fire and were destroyed at a port in New Jersey after Hurricane Sandy. It is believed that flooding caused a short circuit in one of the Karma's lithium-ion batteries, leading to a thermal runaway condition. The fire then spread, eventually igniting the 15 adjacent vehicles [14].

In 2013, two Tesla Model S sedans caught fire while being driven in the United States. The first, in Washington State, occurred after the car struck a metal object in the road. The second occurred after the car ran over a trailer hitch lying on the road in Tennessee. In both cases, road debris punctured the floor and battery pack, leading to battery failure and thermal runaway. Both drivers were able to pull over and exit the cars safely. Tesla said it would add underbody shielding to help protect the lithium-ion battery [15]. In 2014, a fire occurred when the driver, a car thief, crashed the car at high speed, tearing the vehicle in two. The battery pack was ejected and caught fire. The driver later died in the hospital from injuries sustained in the crash [16].

Real-World Safety

Due to the extra weight of RESS, hybrids are 10 percent heavier on average than their non-hybrid counterparts. Provided that the vehicle has good crashworthiness, this extra mass provides a slight safety advantage in some types of crashes, such as those involving other vehicles. A study by the Highway Loss Data Institute estimated the odds that a crash would result in injuries if people were riding in a hybrid vehicle versus the conventional version of the

same vehicle [17]. The analysis included more than 25 hybrid-conventional vehicle pairs, all 2003-11 models, with at least one collision claim and at least one related injury claim filed under personal injury protection (PIP) or medical payment (MedPay) coverage in 2002-10. Both PIP and MedPay are first-party insurance that cover the costs of injuries to drivers and their passengers in the insured vehicles. Figures 4 and 5 compare the injury odds of hybrids with their conventional counterparts under both types of insurance and show that the odds of injury are at least 25 percent lower in hybrids. The differences in injury odds may have been partly influenced by differences in how, when, and by whom hybrids are driven in comparison with their counterparts that are not completely captured by the covariates in the analysis. Nevertheless, these results indicate that electric drivetrains do not pose an overall increased risk of injury for their occupants.

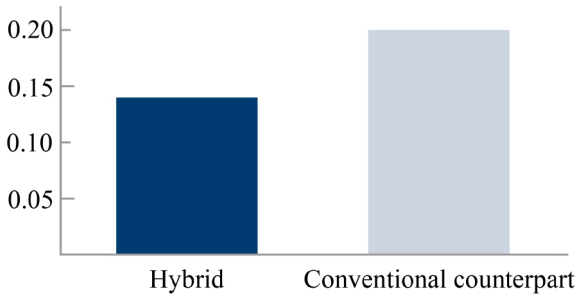

Figure 4. Estimated injury odds under collision and personal injury protection coverage.

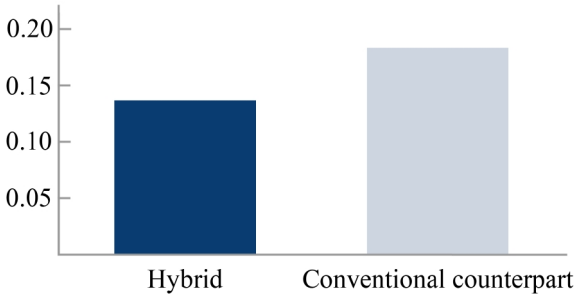

Figure 5. Estimated injury odds under collision and medical payment coverage.

Additionally, IIHS conducted a study of fatal vehicle crashes associated with a fire for model year 2009-14 vehicles [18]. The rate of fire incidences for electric and hybrid vehicles was comparable with those for conventionally powered vehicles.

ELECTRIC/HYBRID VEHICLE TESTS

Battery Testing Standards

There are numerous standards that address the safety of batteries and RESS at the component level such as the Society of Automotive Engineers (SAE J2464, J2929, and J2380), United Nations Economic Commission for Europe (ECE R.100), and draft Global Technical Regulation No.13 for RESS [19-20]. All prescribe tests that simulate various environmental, mechanical, and electrical conditions that batteries and RESS can be subjected to in the automotive environment including:

- Vibration
- Thermal shock and cycling
- Mechanical impact, integrity, and shock
- Fire resistance
- External short circuit protection
- Over- and under-charge protection
- Over-temperature protection

Generally, the standards specify that the battery or RESS shall not leak electrolyte, rupture, catch fire, or explode when subjected to the conditions of each test. The isolation resistance is measured between the positive and negative terminals and the battery case/ground to ensure the internal integrity of the battery or RESS has not been compromised. The isolation resistance should exceed 100 Ω/V, following procedures described in the standards.

In the United States, Federal Motor Vehicle Safety Standard (FMVSS) No. 305 [21] addresses the crash safety of RESS through full-vehicle crash tests. Specifically, FMVSS 305 requires that following regulatory compliance frontal barrier, rear moving barrier, and side moving deformable barrier crash tests:

- RESS shall remain attached and secured in the vehicle, with no intrusion into the occupant compartment
- Electrical isolation of the RESS must be no less than 500 Ω/V
- Any electolyte spillage shall not enter the occupant compartment nor exceed 5 liters outside the occupant compartment.

FMVSS 305 does not impose separate requirements for RESS internal integrity, as this is covered by the aforementioned standards.

Laboratory Vehicle Tests

The Insurance Institute for Highway Safety (IIHS) and Australasian New Car Assessment Program (ANCAP) have crash tested 42 hybrid and/or electric vehicles in various test scenarios. IIHS performs vehicle crashworthiness evaluations using the following tests:

1. Moderate overlap front crash test (64 km/h, 40 percent overlap on driver side, into deformable barrier)
2. Small overlap front crash test (64 km/h, 25 percent overlap on driver side, into rigid barrier with radius on the right edge)
3. Side crash test (50 km/h, deformable mobile barrier into driver side)
4. Roof strength (quasi-static loading on either driver or passenger side of vehicle)

Ratings of good, acceptable, marginal, or poor are awarded to the vehicle in each test mode. The crash test ratings are based not only on measurements made by sensors in the test dummy but also analysis of the dummy's observable motion and measurements of safety cage deformation. The roof crush test is evaluated by measures of crushing force and displacement of the crushing platen [22].

ANCAP performs similar tests as part of its 'Star' rating evaluation program that include:

1. 40 percent frontal offset test (64 km/h on driver side)
2. Side impact test (50 km/h, mobile deformable barrier crashing into driver side of vehicle)
3. Pole side impact test (29 km/h, driver side of vehicle into rigid pole)

The IIHS and ANCAP side impact tests differ in that the deformable barrier used in the IIHS side test has a mass of 1,500 kg and is shaped like an SUV, whereas the ANCAP side impact barrier is shaped like passenger car with a mass of 950 kg.

The results of the three vehicle crash test scenarios above contribute to the ANCAP overall star ratings, which range from 1 to 5 stars. In addition to the vehicle crash tests, ANCAP performs a pedestrian protection assessment, a whiplash protection assessment, and reviews the inclusion of safety assist technology on the vehicle in order to derive the ANCAP overall star rating for the vehicle. The ANCAP rating covers three vehicle safety areas: occupant protection, pedestrian protection, and safety assist technology [23].

Figures 6-9 compare the ratings of plug-in electric (PEV) and hybrid electric (HEV) vehicles with the ratings of conventional vehicles in the same vehicle classes and model years. The electric/hybrid vehicles have a higher proportion of good IIHS ratings in the moderate overlap front test, side impact test, and roof strength test than conventionally powered vehicles from the same vehicle classes and model years. In addition, several HEVs and PEVs have been awarded IIHS *Top Safety Pick* awards, indicating they have the highest level of overall safety according to IIHS guidelines (Table 1).

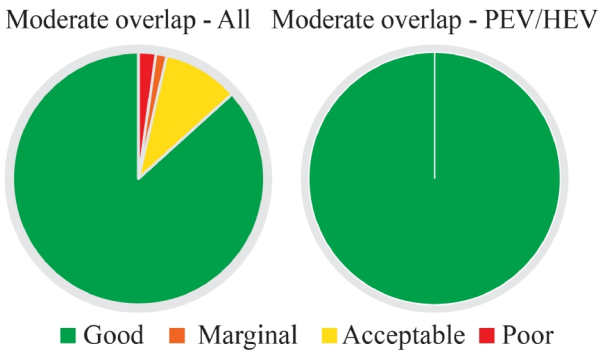

Figure 6. IIHS moderate overlap test ratings.

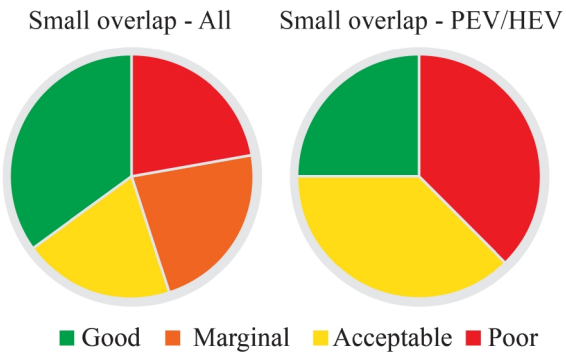

Figure 7. IIHS small overlap test ratings.

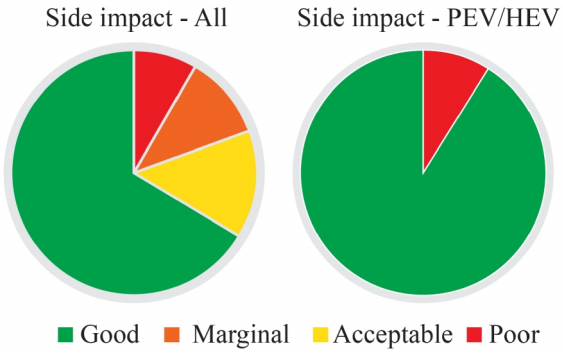

Figure 8. IIHS side impact test ratings.

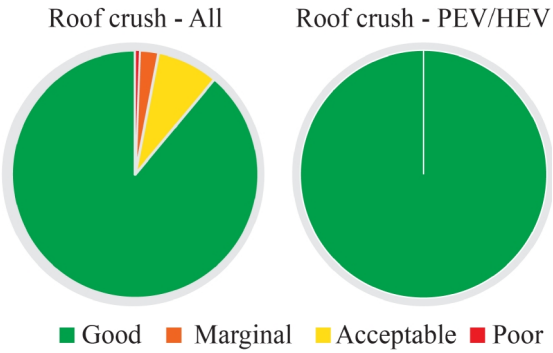

Figure 9. IIHS roof crush test ratings.

Table1
***Top Safety Pick* awards for PEV/HEV tested by IIHS.**

	2009	2010	2011	2012	2013	2014	2015
Chevrolet Volt			x	x	x	x	x
Ford C-Max Hybrid						x	x
Honda CRZ				x	x		
Honda Insight				x	x		
Lexus CT200h			x	x	x		x
Nissan Leaf			x	x			
Toyota Prius	x		x	x	x	x	x
Toyota Prius C				x			
Toyota Prius V				x	x		x

Three IIHS small overlap crash tests of electric/hybrid vehicles resulted in poor structural ratings, and six IIHS side impact tests resulted in acceptable structural ratings. However, the area surrounding the vehicle's high-voltage battery (RESS) was intact in all cases, with no electrical safety issues (Figures 10-12). Moreover, of the 12 HEV/ PEV models tested since IIHS incorporated a 2-week post-test observation period, none have caught fire like the Chevrolet Volt tested by NHTSA.

For the ANCAP tests, only the 2010 Mitsubishi i-MiEV scored lower than the maximum 5 star ANCAP rating, with a final rating of 4 stars. The rating was influenced by occupant injury risk, rather than structural performance of the vehicle, and no crashworthiness deficiencies related to electrical safety were identified as part of the usual assessment.

Figure 10. RESS location in 2013 Toyota Prius C after IIHS small overlap test, side view.

Figure 11. RESS location in 2014 Nissan Leaf after IIHS small overlap test, bottom view.

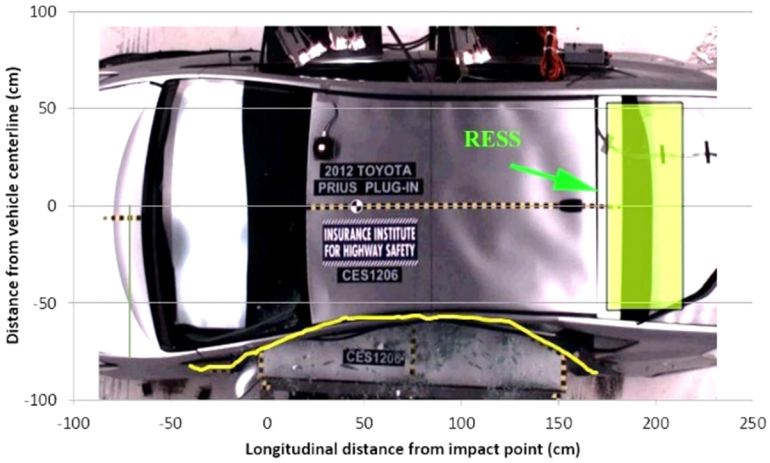

Figure 12. RESS location in 2012 Toyota Prius Plug-In during IIHS small overlap test, overhead view with intrusion chart.

Laboratory Safety for HEV/PEV Crash Testing

HEV/PEV crash test procedures utilized by IIHS and ANCAP have evolved since these vehicles were first introduced in the mass market. There are no specific SAE or other guidelines on crash testing such vehicles; instead, IIHS and ANCAP have evaluated the best practices utilized by automakers and other testing organizations and developed them into a single procedure. It is anticipated that these procedures will continue to evolve as new types of HEV/PEVs enter the market. This section describes the procedures adopted to evaluate the crashworthiness of HEV/PEV vehicles.

Test procedures include monitoring the battery temperature, electrical isolation of the RESS from the vehicle chassis, and verifying that automatic battery disconnection from the drive circuit has occurred after a crash. In addition, as fires caused by RESS damage may occur, a fire management plan has been implemented. Finally, proper discharging and disposal procedures are followed before discarding the vehicle.

Laboratory safety when working on vehicles that include a high-voltage RESS requires the use of protective gear and tools designed for high-voltage work. Eye protection (safety goggles) and insulated gloves and boots should be worn by personnel working with an HEV/PEV RESS. In addition, hand tools should be adequately insulated and, where applicable, include cross-guards to prevent hands from slipping on to any uninsulated part (Figure 13). Finally, high-voltage tool kits should include an insulated pole with a hook or loop that can be used by a second person to pull away a technician who may come in contact with the high-voltage source despite precautions (Figure 14). High-voltage work kits are available from major tool suppliers.

Safely preparing an HEV/PEV for an IIHS crash test requires gathering information about the electric drive system from the test vehicle manufacturer and having a detailed checklist of procedures to follow (Appendix A). The following information can facilitate safe installation of monitoring systems and post-crash disposal of the tested vehicle:

- Location of the manual service disconnect (MSD)
- Locations of the RESS and high-voltage wiring
- Recommended connection locations for monitoring RESS isolation
- Instructions for charging/discharing the RESS
- Information about the chemical properties of the battery coolant
- Information about the color and location of the battery coolant
- Copy of the Material Safety Data Sheet for the battery or its components
- Information about hazards unique to the test vehicle's partiular RESS

Figure 13. Assortment of high-voltage tools.

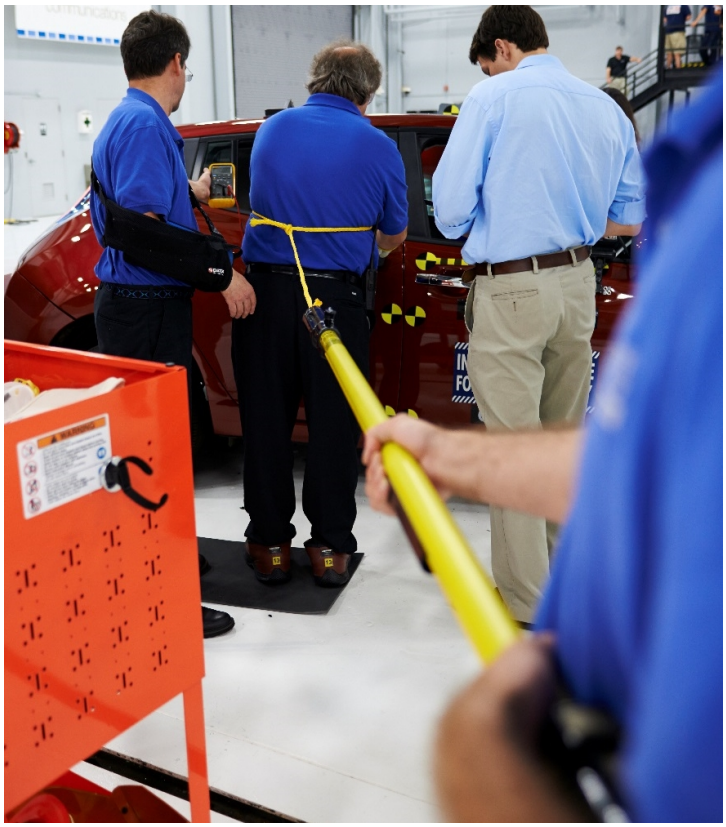

Figure 14. Insulated pole, shown attached to technician measuring high-voltage battery isolation.

Preparation of an HEV/PEV for a crash test begins with using the MSD to isolate the RESS from the vehicle chassis while test equipment is installed and pre-crash measurements are taken. Locations of the MSD are not standardized and vary considerably (Table 2 and Figures 15-16).

Table2.
Examples of locations for manual service disconnects on HEV/PEV.

Model(s)	Location	Notes
Chevrolet Volt	Rear of center console	Accessed through panel inside console
Ford C-Max	Behind and under left rear seat	Rear seat must be folded fully forward
Lexus CT 200h (also Toyota Prius and Prius V)	Rear cargo area	Remove spare tire cover and foam tool bin
Mitsubishi i-MiEV	Under rear of front passenger seat	Move front passenger seat fully forward
Nissan Leaf	Center tunnel in rear seating area	Remove bolted cover
Toyota Prius C	Under rear seat cushion	Remove cushion and access panel
Toyota Prius V	Within center console	Remove center console fascia then remove plastic MSD cover

A clear means of identifying the MSD status should be adopted so that all personnel can know when the vehicle is safe to work on. For example, IIHS practice is to secure the MSD key/plug to the roof of the test vehicle with orange tape (Figure 17). Personnel should consider the RESS to be connected to the drive system if this indicator is absent.

Figure 15. Manual service disconnect in Lexus CT200h, shown in cutaway.

Figure 16. Manual service disconnect in Chevrolet Volt, shown in cutaway.

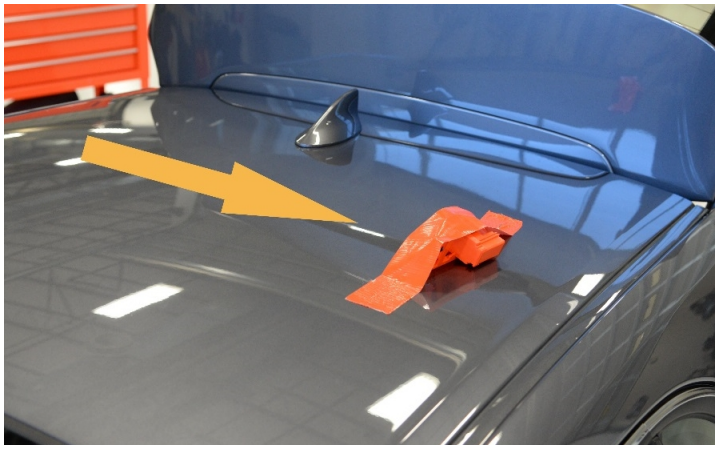

Figure 17. MSD taped to roof of Lexus CT200h while work is conducted to battery system.

For IIHS tests, a monitoring circuit, as described in FMVSS 305, is installed across the positive and negative leads on the drive side of the MSD. This attachment allows the post-crash measurements to ascertain whether the crash-initiated disconnection of the RESS from the drive system has occurred. The IIHS box that contains this circuit also contains circuitry to monitor a thermocouple that is attached to the RESS housing to help identify the potential for post-crash fire events. Figure 18 shows the schematic diagram of the IIHS RESS monitor. Figure 19 illustrates how test probe terminals are protected from accidental contact by technicians and test witnesses. Care should be taken not to interfere with the RESS of high-voltage wiring when installing other test equipment (e.g., data acquisition system, cameras, and related power supplies).

The first check after a crash test is to confirm isolation of the high-voltage power source from the vehicle chassis. This is done by measuring the voltage between the various test points on the monitor. If a non-zero potential is measured, then the isolation resistance is calculated by switching in the known resistors and using the re-measured voltages in the formulas shown in Figure 18.

An isolation resistance of more than 500 Ω/V is considered safe and would represent compliance with FMVSS 305 following regulatory tests. This measurement confirms the high-voltage battery is isolated from the vehicle body. Simultaneously and from a distance, other laboratory personnel visually check for signs of smoke or coolant leakage. Once electrical isolation of the RESS is established, collection of any leaking coolant may begin. Temperature of the RESS housing is monitored throughout post-crash procedures. As an extra precaution, the MSD should be removed as soon as it is accessible to test personnel.

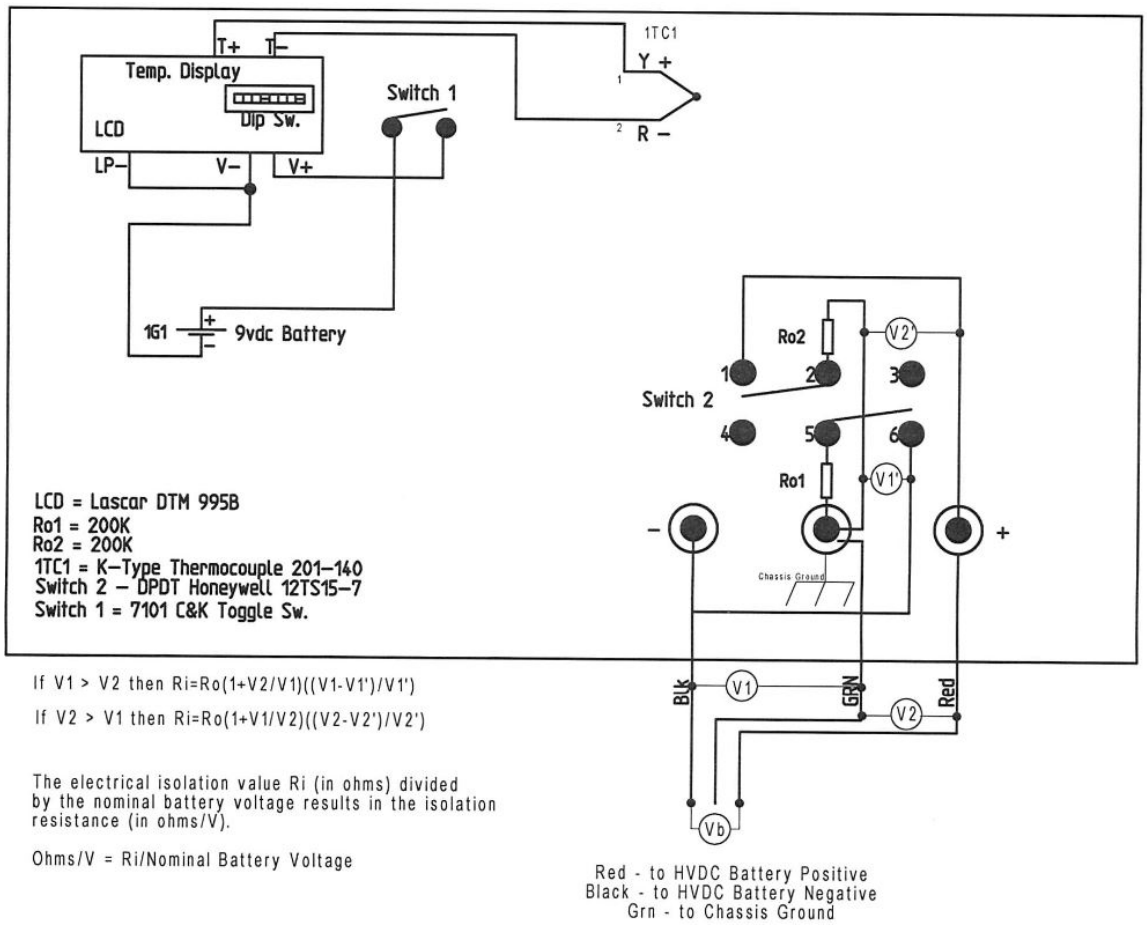

Figure 18. Schematic of IIHS '305' box, including thermocouple circuit and isolation resistance formula.

Figure 19. IIHS '305' box, showing thermocouple readout, resistor switch, and terminal cover.

In the event of any sign of fire or rising temperatures at the RESS housing, the vehicle should immediately be moved out of the laboratory if it is safe to do so. This can be managed with a lift truck equipped with insulating material on its forks to shield both the lift and its operator from potential electric shock. Fire extinguishing operations should commence immediately. Extinguishing fires associated with both nickel metal hydride (Ni-MH) and lithium-ion (Li-Ion) batteries typically involves applying copious amounts of water, although there is conflicting advice amongst some manufacturers regarding how to best handle a fire event; for example, instructions for the Toyota Prius C and Prius V are to let the battery burn itself out [24]. Regardless, as an additional precaution, it is good practice to arrange for the local fire department to be present during crash tests of HEV/PEV, especially those with Li-Ion batteries.

Another hazard associated with damage to high-voltage batteries is the possible release of carbon monoxide, hydrogen fluoride, and other harmful gases. Gas detection equipment can be used to check for their presence after a test, but this equipment is very expensive and the release of gases is unlikely in tests conducted by IIHS and ANCAP. The potential hazard may be managed by moving the vehicle to a well-ventilated area. A release of gas typically indicates a serious problem within the RESS.

Since the post-crash fire from the Chevrolet Volt test was reported by news media, IIHS has included an additional precaution and evaluation of this potential risk. Tested HEV/PEVs are stored for a period of 2 weeks in a metal storage shed located remote from the test laboratory (Figure 20). This minimizes the risk of collateral damage in the unlikely event of a fire. After this observation period, the vehicle's high-voltage battery is discharged per the manufacturer's recommended procedure.

Figure 20. Electric/hybrid vehicle post-test storage.

CONCLUSIONS

Neither ANCAP nor IIHS crashworthiness testing has identified safety-related issues associated with the high-voltage RESS of electric and hybrid vehicles. In fact, test results suggest that, as a class, these vehicles are more crashworthy than their conventionally powered counterparts. However, the number of crash tests of vehicles with electric drive systems is small compared with ANCAP and IIHS experience with conventional vehicles, and there are crash test scenarios not covered by the crash tests conducted by ANCAP and IIHS. For example, higher speed narrow object impacts may intrude into the battery compartment. As the availability of these vehicles increases, it seems likely that crash testing may uncover problems unique to these vehicles.

Crash testing has been executed safely through careful attention to the unique hazards associated with high-voltage batteries. However, new types of electric powertrains (e.g., fuel-cells) are being introduced into the market, so laboratory safety practice will need to evolve. Current electric/hybrid safety procedures may be a good starting point when developing them.

Additional information regarding the safety precautions used when testing electric/hybrid vehicles can be found in "Safety Precautions and Assessments for Crashes Involving Electric Vehicles" [24].

REFERENCES

[1] U.S. Department of Energy. 2014. Alternative fuels data center. Available: http://www.afdc.energy.gov/data/. Accessed: 2 Mar 2015.Washington, DC.

[2] Pontes, J. 2014. EV sales; Australia December 2013. EV-Sales.blogspot.ca, Jan 18. Available: http://www.ev-sales.blogspot.ca/2014/01/australia-december-2013.html. Accessed: 2 Mar 2015.

[3] Pontes, J. 2015. EV sales; Australia full year 2014 (updated). EV-Sales.blogspot.ca, Jan 15. Available: http://ev-sales.blogspot.com.br/2015/01/australia-full-year-2014.html. Accessed: 2 Mar 2015.

[4] Dowling J. 2011. Mitsubishi electric car back in stock. Carsales.com.au. Available: http://www.carsales.com.au/news/2011/small-passenger/mitsubishi/mitsubishi-electric-car-back-in-stock-26567. Accessed: 2 Mar 2015. Victoria, Australia.

[5] Pontes, J. 2013. EV sales; Australia full year 2012. EV-Sales.blogspot.ca, Jan 5. Available: http://www.ev-sales.blogspot.ca/2013/01/australia-full-year-2012.html. Accessed: 2 Mar 2015.

[6] Ottley S. 2013. Hybrid car sales make up 1 per cent of vehicle sales. *The Sydney Morning Herald*, Nov 30. Available: http://www.smh.com.au/national/hybrid-car-sales-make-up-1-per-cent-of-vehicle-sales-20131129-2ygw9.html. Accessed: 2 Mar 2015.

[7] Nicholson T. 2014. Toyota hits new hybrid high. GoAuto.com.au, Mar 27. Available: http://www.goauto.com.au/mellor/mellor.nsf/story2/A19B001FC141478ECA257CA800178264. Accessed: 2 Mar 2015.

[8] Bober I. 2014. Hybrid sales flopped in 2013. *Practical Motoring*, Jan 21. Available: http://practicalmotoring.com.au/car-news/hybrid-sales-flopped-2013/. Accessed: 2 Mar 2015. New South Wales, Australia: Practical Motoring.

[9] Pettendy M. 2014. New Mazda2 to plug in. Motoring.com.au, Jun 30. Available: http://www.motoring.com.au/news/2014/small-passenger/mazda/2/new-mazda2-to-plug-in-44423. Accessed: 2 Mar 2015. Victoria, Australia.

[10] TMR Team. 2013. Toyota's greenest Camry surpasses Prius in Australian hybrid sales. *The Motor Report*, Apr 10. Available: http://www.themotorreport.com.au/56320/toyotas-greenest-camry-surpasses-prius-in-australian-hybrid-sales. Accessed: 2 Mar 2015.

[11] Martin S. 2012. Cool and green hybrid car sales surge to Australian record. News.com.au, Aug 2. Available: http://www.news.com.au/finance/cool-and-green-hybrid-car-sales-surge-to-australian-record/story-e6frfm1i-1226441599395. Accessed: 2 Mar 2015. New South Wales, Australia.

[12] Australian Business Journal. 2015. Drivers going green as hybrid cars sales soar. TheAuBJ, Aug 2. Available: http://www.australianbusinessjournal.com.au/drivers-go-green-as-sales-of-hybrid-cars-soar/. Accessed: 2 Mar 2015. Victoria, Australia.

[13] Crawley J. 2012. Probe of Chevy Volt fires closed. Reuters, Jan 20. Available: http://www.reuters.com/article/2012/01/ 21/us-gm-volt-idUSTRE80J20X20120121. Accessed: 2 Mar 2015.

[14] Lienert A. 2012. Fisker reveals cause of Karma fires during Hurricane Sandy. Edmonds.com, Nov 6. Available: http://www.edmunds.com/car-news/fisker-reveals-cause-of-karma-fires-during-hurricane-sandy.html. Accessed: 2 Mar 2015.

[15] Ivory D. 2014. Federal safety agency ends its investigation of Tesla fires. *The New York Times*, Mar 28. Available: http://www.nytimes.com/2014/03/29/business/safety-agency-ends-investigation-of-tesla-fires.html. Accessed: 2 Mar 2015.

[16] Burke K. 2014. Driver of stolen Tesla that crashed, split in 2, dies. *Automotive News*, Jul 10. Available: http://www.autonews.com/article/20140710/OEM11/140719991/driver-of-stolen-tesla-that-crashed-split-in-2-dies. Accessed: 2 Mar 2015. Detroit, MI: Crain Communications Inc.

[17] Highway Loss Data Institute. 2011. Injury odds and vehicle weight comparison of hybrids and conventional counterparts. *HLDI Bulletin* 28(10). Arlington, VA.

[18] National Highway Traffic Safety Administrations. 2015. Fatality Analysis Report System. Available: http://www.nhtsa.gov/FARS. FARS data, February. Washington, DC: U.S. Department of Transportation.

[19] Society of Automotive Engineers. 2014. Safe handling of high-voltage battery systems. Classroom training, Course ID C1019. Available: http://training.sae.org/seminars/c1019/. Accessed: 2 Mar 2015. Warrendale, PA.

[20] Society of Automotive Engineers. 2015. Impact and Rollover Test Procedures Standards Committee meetings. Available: http://www.sae.org/works/committeeHome.do?comtID=TEVSSTS1. Accessed: 2 Mar 2015. Warrendale, PA.

[21] Office of the Federal Register. 2011. *Code of Federal Regulations*; Title 49 Transportation, Part 571 Federal Motor Vehicle Safety Standards, Standard No. 305 Electric-powered vehicles: electrolyte spillage and electrical shock protection. Washington, DC: National Archives and Records Administration.

[22] Insurance Institute for Highway Safety. 2015. About our tests. Available: http://www.iihs.org/iihs/ratings/ratings-info/frontal-crash-tests. Accessed: 2 Mar 2015. Arlington, VA.

[23] Australasian New Car Assessment Program. 2015. ANCAP safety ratings explained. Available: http://www.ancap.com.au/safety-ratings-explained. Accessed: 2 March 2015. Manuka, Australia.

[24] Paine M, Paine D, Ellway J, Newland C, Worden S. 2011. Safety precautions and assessments for crashes involving electric vehicles. Paper no. 11-0107. *Proceedings of the 11th International Technical Conference on Experimental Safety Vehicles*. Washington, DC: National Highway Traffic Safety Administration.

Appendix A – Electric Vehicle Supplemental Checklist (IIHS)

INSURANCE INSTITUTE FOR HIGHWAY SAFETY VEHICLE RESEARCH CENTER	CHECKLIST	Page: 1 of 2	Electric Vehicle Supplement	COORDINATOR
Safety Measures and Tasks			**CENXXXX**	

This checklist covers safety related tasks and pre and post-crash measurements.	Vehicle:
!! HIGH VOLTAGE SYSTEMS ARE NEVER SAFE, THEY CAN ONLY BE CONSIDERED SAFER !!	VIN:

Initial	Date	Checklist Items
Pre-Test (before vehicle prep)		
		Type of propulsion battery (e.g. Li-Ion, NiMH, etc.) _____.
		Manufacturer instructions for installing '305' isolation box received and satisfactory
		Copy/Paste 'Battery Isolation Worksheet' (Crashworthiness/ElectricVehicleInformation) into test Data folder
		Nominal HV battery voltage _____V & resistor needed for '305' box (at least 500 times nominal battery voltage) _____ Ω
		Verify propulsion battery is at full state of charge, per readout (varies by car; all but one 'bar' is typically sufficient)
		Color of HV battery coolant (for leak detection, post-crash)
Pre-Test Prep (Vehicle)		**!!! Appropriate Personal Protective Equipment to be worn at ALL TIMES !!**
		Remove positive cable from battery (12v) and then the HV service disconnect (MSD)
		Tape MSD to roof of vehicle with orange tape !! **MSD is to be taped to roof of vehicle whenever it is not installed in the HV battery!!**
		Install '305' box, per manufacturer instructions **OR** request OEM to install if installation is deemed too hazardous **(Caution; the 305 box is now essentially part of the HV system)**
		Install thermocouple on battery (or as close as possible to actual battery housing)
		Photograph wiring hook-up and routing
		Check voltage of + and – terminal to vehicle body; both should be zero. If not, STOP and contact manufacturer!
		Install service disconnect
		Check battery isolation, using Battery Isolation Worksheet. If results are more than 500 Ω/V, **remove service disconnect & tape to roof** and continue…..
		Remove accelerator cable/connector
		Fabricate a locking plate to hold transmission in 'Neutral' during crash
		Verify area surrounding HV battery is clear of metal shavings, tools, loose cables, etc.
		Schedule Fire Department to be on hand during test if vehicle contains Li-Ion battery
		Verify all HV safety equipment is in Crash Hall and easily accessible, the emergency egress path for vehicle is clear, and forklift present (with fork isolators attached)

INSURANCE INSTITUTE FOR HIGHWAY SAFETY VEHICLE RESEARCH CENTER	CHECKLIST	Page: 2 of 2	Electric Vehicle Supplement	COORDINATOR
Safety Measures and Tasks			**CEN1453**	

This checklist covers safety related tasks and pre and post-crash measurements.	Vehicle:
!! HIGH VOLTAGE SYSTEMS ARE NEVER SAFE, THEY CAN ONLY BE CONSIDERED SAFER !!	VIN:

Initial	Date	Checklist Items
Pre-Test (Shed)		**!!! Appropriate Personal Protective Equipment to be worn at ALL TIMES !!**
		Prior to Final Checklist, install the service disconnect
		Record battery isolation, using Battery Isolation Worksheet in Excel (Pre-test). If results are more than 500 Ω/V, continue with final checklist
Post-Test (Crash Hall)		*****Perform Steps Prior to Human Contact With Vehicle*****
		INFORM PEOPLE ON FLOOR TO NOT TOUCH THE VEHICLE UNTIL THE ALL CLEAR IS GIVEN!!
		Verify there is no toxic gas venting – visual
		Verify there is no smoke or fire coming from battery
		Verify there is no battery coolant leakage
		Record battery temperature (thermocouple reading) _____°F. Continue to monitor for increase using thermal imager and by monitoring temperature readout
		Check battery isolation, using Battery Isolation Worksheet in Excel (Post-test). ☐ Greater than 500 Ω/V, continue…. ☐ Less than 500 Ω/V means a potential isolation loss; quarantine vehicle and continue to monitor…….
		Continue to monitor battery temperature and isolation for 5 minutes. If stable ⇨
		Continue with typical post-crash analysis
		Remove service disconnect if possible & tape to roof
		DO NOT LEAVE VEHICLE IN BUILDING UNATTENDED AT ANY TIME!
Post-Test (Photo Studio)		**!! Appropriate Personal Protective Equipment to be worn at ALL TIMES !!**
		Remove service disconnect as soon as possible & tape to roof
		Remove '305' box
		If vehicle has Li-Ion propulsion battery, have observer present when the vehicle is in the building. Move vehicle to secure area outside at end of day (DO NOT LEAVE IN BUILDING UNATTENDED AT ANY TIME!). Vehicle will be quarantined in secure area, with fully charged battery, for at least 2 weeks before allowing manufacturer to discharge it
		If vehicle propulsion battery is not Li-Ion, the battery should be discharged by manufacturer ASAP and before vehicle is sold for scrap (alternatively, the OE's can take possession of the battery)

HOWSAFEISYOURFIRSTCAR.COM.AU – A WEBSITE TO ASSIST YOUNG DRIVERS TO FIND A SAFE CAR, IN THEIR BUDGET.

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Paper Number 15-0306

ABSTRACT

Young drivers constitute approximately 13% of all license holders, yet they represent around 25% of drivers killed each year. Although gains have been made in reducing the number of young people being killed and seriously injured on our roads, they continue to be overrepresented in fatal and serious injury crashes each year.

Research has demonstrated that young drivers are at greater risk because they are inexperienced and more likely to take risks on the road.

Some of the factors that increase the risks of crashing among young drivers include:

- Driving with peer aged passengers
- Night time driving
- Use of mobile phones
- Drink/drug driving
- Speeding
- Driving older and less safe cars

Research shows that young drivers tend to drive the least safe and oldest cars on our roads. Research from the Monash University Accident Research Centre (2009) demonstrated that:

- Both female and male young crash-involved drivers are driving older vehicles than their older counterparts.
- Young males are driving older vehicles than females.
- Young female drivers are driving smaller vehicles than their older counterparts.
- Crashworthiness of cars driven by younger drivers is poorer than for older drivers.
- Young female's cars are less crashworthy than young male's cars.

An annual survey from the Transport Accident Commission (TAC) demonstrates that 24% of 18-25 year olds intend to buy a new car, 51% intend to purchase a used car and 25% are undecided. Safety features rank second in importance for 18-25 year olds after condition of vehicle (and price). 67% of 18-25 year olds say they will consider crash test results or safety ratings before purchasing a car, compared to 71% of 26-39 year olds, 64% of 40-60 year olds and 87% of 61+ year olds. 23% of 18-25 year olds say they will not consider safety ratings, and 11% don't know.

In addition to other initiatives to improve young driver safety, including a graduated licensing scheme and school based road safety education, the TAC has now developed a website to make it easier for young drivers to find a safe car within their budget. The website allows users to search through a database of cars that have a 4 or 5 star Australasian New Car Assessment Program (ANCAP) rating or Used Car Safety Rating (UCSR) and are approved by the roads authority for probationary license holders to drive. Users can search by price ranges starting from as low as $2,500 to find a safe car, within their budget.

This paper will detail the background research, development of the website, including data used, marketing strategies and an early evaluation.

INTRODUCTION

In Victoria, Australia, young drivers aged between 18 and 25 years old, constitute approximately 13% of all licence holders, yet they represent around 20-25% of drivers killed each year. This is a trend that is seen in many other jurisdictions globally. Although gains have been made in reducing the number of young people being killed and seriously injured on our roads, they continue to be overrepresented in fatal and serious injury crashes each year.

There are many factors that increase the risks of crashing among young drivers including:

- Driving with peer aged passengers
- Night time driving
- Fatigue
- Use of mobile phones and other distractions
- Drink and drug driving
- Speeding

Another important factor that plays a role in crash avoidance and injury severity is the car that a young person is driving. Research from the Monash University Accident Research Centre (MUARC) [1] demonstrates that:

- Both female and male young crash-involved drivers are driving older vehicles than their older counterparts.
- Young males are driving older vehicles than females.
- Young female drivers are driving smaller vehicles than their older counterparts.
- Crashworthiness of cars driven by younger drivers is poorer than for older drivers.
- Young female's cars are less crashworthy than young male's cars.

An annual survey by the Social Research Centre for the Transport Accident Commission (TAC) demonstrates that the majority of (51%) young people are looking to purchase a used car rather than new (24%) however 25% were undecided [2]. Safety features rank second in importance for 18-25 year olds after condition of vehicle (and price). 67% of 18-25 year olds say they will consider crash test results or safety ratings before purchasing a car, compared to 71% of 26-39 year olds, 64% of 40-60 year olds and 87% of 61+ year olds. 23% of 18-25 year olds say they will not consider safety ratings, and 11% don't know.

Based on research that indicated the low level of protection provided by the cars young people tend to drive, Victorian road safety organisations, the TAC, VicRoads and the Royal Automobile Club of Victoria (RACV), sought to promote awareness of the importance of vehicle safety for young drivers, and make it as easy as possible for young drivers and their parents to find a safe car. Safety ratings for used vehicles were already available as Used Car Safety Ratings (UCSR) which are calculated every year by MUARC [3]. However, a key consideration for young people who are purchasing a car is price. It was recognised that to make it as easy as possible for consumers to find a safe car, within their budget, pricing information would need to be provided along with safety ratings.

FIRST CAR LIST

The Victorian road safety organisations engaged a vehicle specifications and pricing information supplier, Redbook, to match UCSR with their database to provide a list of safe (4 or 5 star rated) cars under $14,000. The list of cars was dveloped into a static document that was made available online. The document also included supporting information explaining the UCSR, prohibited vehicles for probationary drivers, crashworthiness ratings, harm to other road users ratings, pricing information. The list was promoted via schools, youth activations and events, and local community organisations.

While the list was very popular, it was difficult to keep up to date and it was recognised that it could be more interactive and useful for young drivers. The list also lacked Australasian New Car Assessment Program (ANCAP) rated vehicles and didn't clearly identify possible probationary prohibitied vehicles. Taking these barriers into consideration it was decided that an online searchable tool would be more useful, easier to update and promote.

HOWSAFEISYOURFIRSTCAR.COM.AU

Following the popularity of the First Car List, the partners investigated the possibility of turning it into a searchable online tool. The TAC managed the project and engaged Redbook to match the latest UCSR data to their database (which already includes VicRoads data on probationary approved vehicles) and develop a search tool to enable safe, probationary approved vehicles to be displayed easily. A website was developed which allowed the TAC to manage the homepage content and additional pages while Redbook managed the search tool and search results.

Essentially, the website and search tool allows users to search through a database of 4 and 5 star UCSR and ANCAP rated cars that are P plater approved, up to $35,000. The user is able to filter by different price ranges, and undertake make/model searches. Further information about the ratings and safety features is also available on the site.

HOWSAFEISYOURCAR.COM.AU

Howsafeisyourfirstcar.com.au is a complementary website to howsafeisyourcar.com.au. howsafeisyourcar.com.au is a broader website which the TAC uses to support its vehicle safety campaigns. Howsafeisyourcar.com.au includes all vehicles sold from 1990 until the present day and their safety feature specifications. Where available it also includes UCSR and ANCAP ratings. Further information is also provided about individual safety features, fleet policies, child restraints and other related vehicle safety information. This website has become quite successful and obtains an average of around 60,000 unique visitors per month when not supported by mass media but reaches around 120,000 unique visitors per month when supported by mass media. howsafeisyourcar.com.au does not currently include pricing information or probationary approved vehicle information.

PROMOTION

Howsafeisyourfirstcar.com.au was launched on October 19 2014. Initially the website was promoted via stakeholders, local community groups and social media. The website is also promoted via the TAC's young driver activation activities and events. The TAC manages a program aimed at young drivers which is based around a large bus, which has been converted into a chill out space for young people. The bus is named Vanessa and attends major festivals and events in Victoria, Australia that have a predominantly young patronage. Vanessa is manned by young people who have received road safety training and information, and have been trained to use police issue breathalyzer machines. The main function of Vanessa is to provide free breath tests to festival patrons to help them to get home safely. Vanessa also provides road safety information, free merchandise, competitions and games to engage with young people. Some competitions, merchandise and information include vehicle safety messages and the howsafeisyourfirstcar.com.au URL.

The TAC has also developed a postcard to be sent to all Learner drivers letting them know about the website. The first mailout will go out in early 2015. Further mailouts will be sent every quarter. Search engine optimization will also be used to promote the website.

EVALUATION

Despite the small amount of promotion the website has had a good amount of unique visitors and page views. Refer to Table 1 for exact numbers.

Table1.
Number of Unique visits and page views by month for howsafeisyourfirstcar.com.au.

Month	Unique Visits	Page Views
October	624	4149
November	527	2890

December	251	1715
January	221	1597
February	342	1675

The TAC will continue to monitor the usage of the howsafeisyourfirstcar.com.au and make improvements.

CONCLUSION

Young drivers are some of the most at risk drivers on Victorian roads, yet they often drive the least safe cars. The aim of howsafeisyourfirstcar.com.au is to provide young drivers and their parents an easy to use tool to easily identify safe cars within their budget. The website was launched in late 2014 and has attracted a good amount of unique visitors and page views. Work will continue to be undertaken by the road safety organisations to promote this website, in a bid to get more young drivers into safer cars.

REFERENCES

1. Whelan, M., J. Scully, and S. Newstead, *Vehicle safety and young drivers: Stages 2 & 3 - Analysis of young driver crash types and vehicle choice optimisation*. 2009, Monash University Accident Research Centre: Melbourne, Australia.
2. Social Research Centre, *The Transport Accident Commission Road Safety Monitor*. 2014: Geelong, Australia.
3. Newstead, S., L. Watson, and M. Cameron, *Vehicle safety ratings estimated from police reported crash data: 2014 update. Australian and New Zealand crashes during 1987-2012*. 2014, Monash University Accident Research Centre: Melbourne, Australia.

APPENDIX 1

Definition of probationary prohibited vehicle

If the vehicle is manufactured before 1 January 2010:

- has an engine with eight cylinders or more, or
- has an engine that is turbocharged or supercharged.
- has an engine that has been modified to increase the vehicle's performance (other than a modification made by the manufacturer in the course of the manufacture of the vehicle, or
- is a nominated high performance six cylinder engine.

If the vehicle is manufactured after 1 January 2010

- has a power to mass ratio of greater than 130 kilowatts per tonne, or
- has an engine that has been modified to increase performance (other than a modification made by the manufacturer in the course of the manufacture of the vehicle)

Manufacture date

The date of manufacture is determined by the date on the vehicle's compliance plate or, in the case of a used import, the "Built" or "Built Date" recorded on a metal plate or component of the vehicle.

The vehicle compliance plate confirms that the vehicle complies with Australian design standards and emissions. The date shown on the compliance plate is the date that the compliance plate was fitted to the vehicle by the manufacturer. With some vehicles, there may be a significant difference between the build date and the date of compliance due to shipping and storage time. The compliance plate may even be fitted in a different year.

The compliance plate can be a silver metal plate or sticker that is attached to the vehicle, usually fitted to the firewall (between the passenger compartment and engine) or in the driver's door jam or boot area.

Exemptions

An exemption from VicRoads allows a probationary licence holder to drive a probationary prohibited vehicle.

The Assessment results of the Advanced Safety Technology in JNCAP and its future

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15-0275

Abstract

The Japanese government has set up the target of fatalities-from-traffic-accidents reduction. Its aim is to be at the safest traffic society in the world. However, the reduction rate of the death toll in Japan has declined but it's still in a severe situation. Moreover, we have a rapidly aging society. This is another problem.

On the other hand, with the rise of a national safety consciousness, many cars equipped with advanced technology are available on Japan's market including the small sized car, so called kei-car and it is in the most diffused situation in the world at a present stage. But more promotion is desired.

Nevertheless, an understanding about a difference of the performance and the characteristic of that technology are not yet understood efficiently.

Although NCAP has so far achieved big success by the technique of the information dissemination to a consumer for improvement in the safety performance of a car, extending this to the domain of advanced safety technology is called for.

JNCAP started advanced safety technology assessment from 2014 based on our roadmap. In 2014, we adjusted the protocol of the procedure of Autonomous Emergency Braking System (AEBS) test, Lane Departure Warning System (LDWS) test and an evaluation method.

In the protocol of an evaluation method, it is prescribed that an official announcement shows the overall points of several results of advanced safety technology assessment.

We are targeting the spread of technology by evaluating various advanced safety technology synthetically and thus more technical development is urged with the digitization technique of evaluating the reduction effect of a deaths and serious injury accidents based on the actual accident data from Japan.

We implemented the assessment according to these protocols and released the result of 37 models in FY2014.

So, various characteristics for every technology became clear as a result of the AEBS tests. Although various technologies, such as laser radar equipment, millimeter-wave radar equipment, mono-eye, dual-eye camera is used, we are able to discuss about the important information we should give to a consumer and the future course of the advanced safety technology depending on current test results.

Finally, I would also like to write about the future work of JNCAP based on the discussion taken in our steering committee meetings and the WGs.

Presently, NCAPs are taking places in every region in the world. In Japan, JNCAP have made a significant progress on road safety. This article includes advanced safety assessment, analysis and results which were started in fiscal year of 2014 and further developed.

1. Background

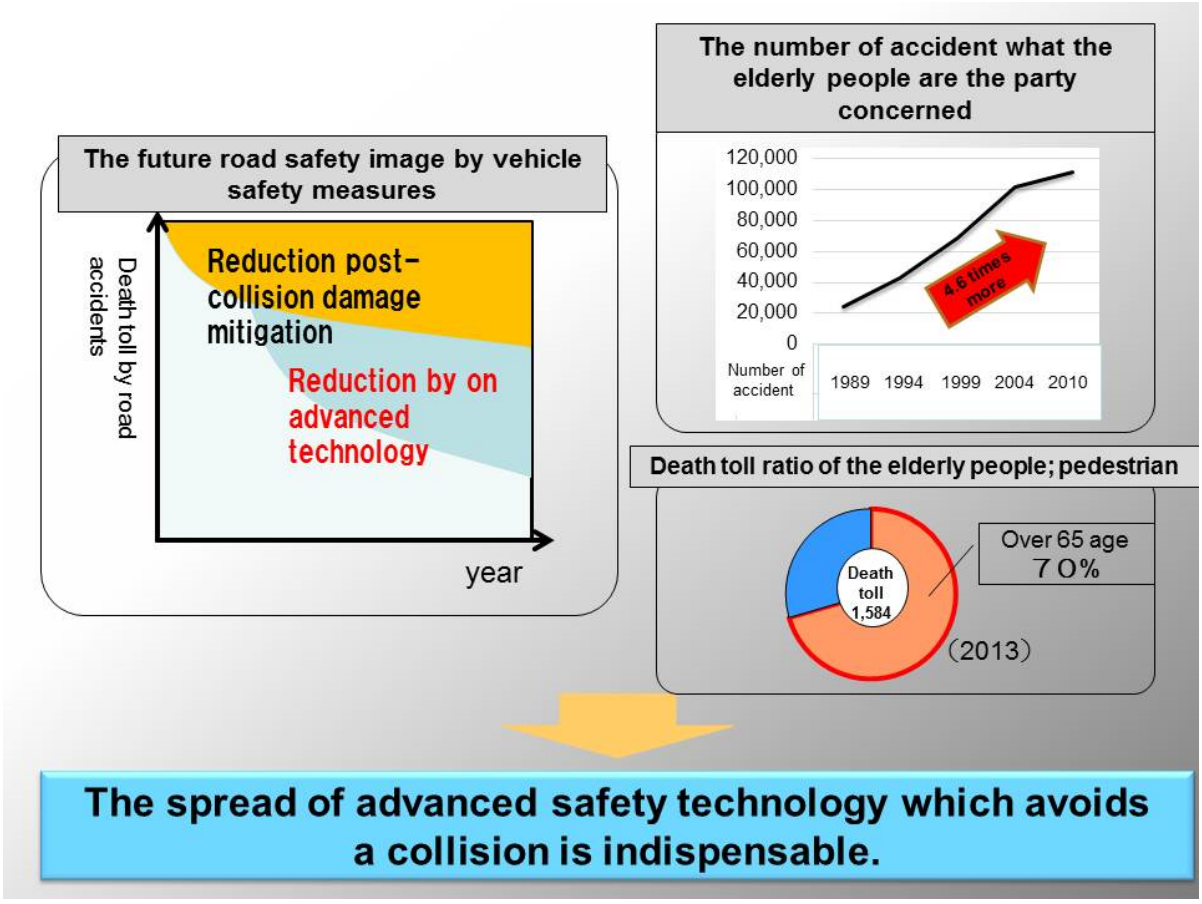
The number of road traffic deaths and serious injuries are declining recently. However, more can be done as the death toll in 2014 was 4,113 and 5,152 if it includes death within 30 days after the accident (data on 2012). NASVA (National Agency for Automotive Safety and Victim's Aid) acts to help those who are seriously injured from the road accidents. The government of Japan now sets the target of reducing death records to less than 2500. Its aim is to have the best road safety record in the world by 2018. MLIT has three measures linking each other on vehicle technical aspects for safety. JNCAP is one of them which is promoted by MLIT (Ministry of

Land, Infrastructure, Transport and Tourism), and NASVA. NASVA, as an exclusive organization, for supporting the seriously injured and their family members it carries out three types of activities; support, prevent and protect which are linked effectively. From fiscal year of 2014, JNCAP carried out passenger safety performance evaluation and pedestrian performance evaluation which prevent collision.

2. Outline of advanced safety performance assessment

To achieve the target that government sets, collision safety technologies are not quite enough. Also, older drivers directly involved in traffic accidents are increasing. Pedestrian death rate becomes over 50% is considerably high, thus clearly shows marked characteristic of an aging society. Meeting these problems, it is necessary to introduce a new safety technology such as AEBS which can avoid collision.

Under this circumstance, JNCAP steering committee has decided to enforce advanced safety technology assessment as one of measures which contributes to reducing deaths and severe injuries.



The steering committee refers to computed data of which the result of calculated the damage reduction effect is used in the ASV project which government promotes to make a roadmap for this technology. Digitization for reduction effects of deaths and injuries were calculated by multiplying relevance factor and safe contribution ratio at the time of system functioning and social loss ratio of death and severe injury is defined as 30:8. The total points of AEBS (car to car) and AEBS (car to pedestrian) refers as 100 points that is most effective.

Evaluation points for advanced assessment
(Forecast on accident reduction effect)

	ＡＳＶ technology	Estimated reduction numbers				total of microdata			main cause
		deaths	severe injuries	reduction effects		deaths	severe injuries	injuries	
(1)	Autonoomous Emergency Brake System(AEBS) [car to car]	**59**	**1,649**	33	100	**59**	**1,664**	164,453	distracted driving Misoperation
(2)	Autonoomous Emergency Brake System(AEBS) [car to pedestrian]	**552**	**1,708**	67		**700**	**2,287**	14,639	distracted driving
(3)	Lane Deoarture Warning System(LDWS)	**67**	**206**	8		**168**	**516**	1,274	distracted driving・traffic condition
(4)	Lane Keep Asist system (LKAS)	**15**	**75**	2		**15**	**75**	260	distracted driving・traffic condition
(5)	Rear View Monitoring System[rear]	**9**	**291**	6		**13**	**415**	3,638	distracted driving

Evaluation points

○The accident reduction effect of ASV technology is based on the macro accident statistical data for H 21（limiting to a passenger car/standard-sized car, and a minicar）

○Reductional effect score are calculated by multiplying the ratio of the social amount of a loss (3.75:1)and the number of and deaths and the serious injuries,then added each other.

○）making the numerical value into 100pt used as a standard by adding the accident reduction effect of car to car (1) car to pedestrian(2).

→Value of one point in the accident reduction effect of death and a serious injury for by system are calculated equarlly on 1 pt by each system

As it shows on our roadmap, we set 2 test protocols, allocation of the points, logo marks for AEBS (car to car) and LDWS and three policies for publication of test results, and started tests and evaluations in fiscal year of 2014.

3. Test procedures and evaluation methods for AEBS (car to car) and LDWS

1) Test procedures and evaluation methods for AEBS

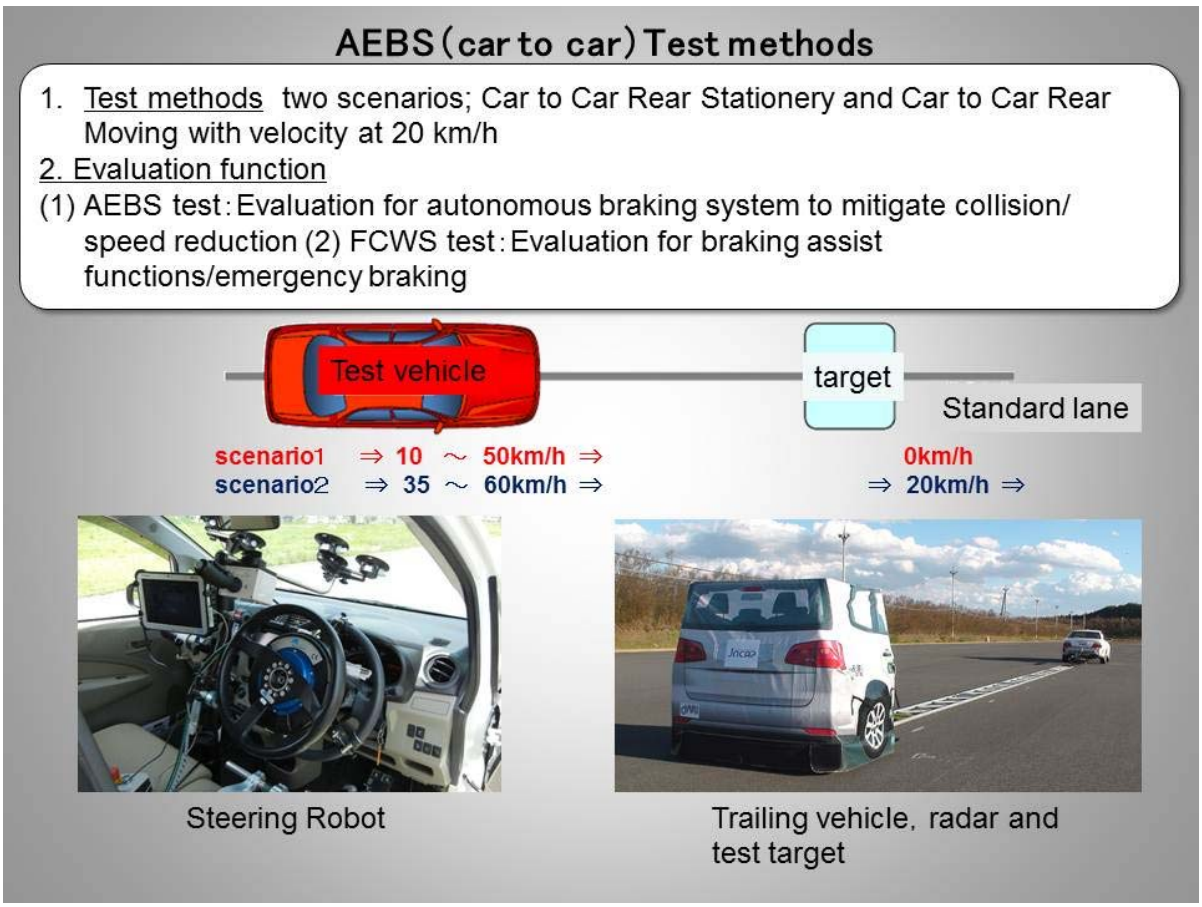
We referred to Euro NCAP's test procedure and modified the evaluating methods for meeting a real Japanese accident condition.

Test scenarios are;

1. CCRs (Car to car rear collision stationery)

2. CCRm at constant speed (Car to car rear collision moving)

The function of each AEBS and Forward Collision Warning System (FCWS) are evaluated. We evaluate the damage mitigation effect by the combination of the alert to a driver, and the brake assisting function in each scenario. In order to examine impartially and properly, we use the steering robot and the accelerator brake robot. We use the same type of target as EuroNCAP representing vehicles back to sensing technology, such as radar and a camera. It is what can absorb a shock at the time of a collision.



Each scenario, evaluating functions and speed reduction rate in each speed category are calculated with evaluation methods. (if collision is mitigated it refers as 1) are allocated this real accident data and adds up the total as for evaluation methods. All the marks are based on the forecast of the reduction effects of accidents by the government and the full marks for AEBS for car to car is 33 points. However, because of the safety reason, tests speed of 55km/h and 60 km/h are not carried out at the CCRs scenario, therefore total score at present is 32 points.

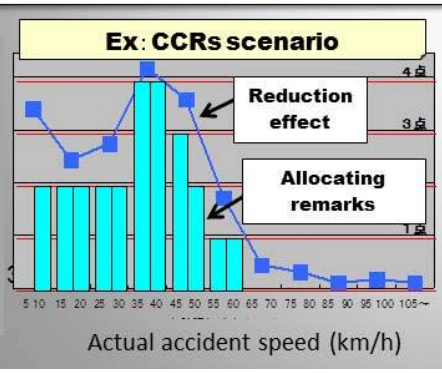
AEBS test and evaluation

3. The index of evaluation
tested with each scenario speed by 5-km/h for every function (Max.34 conditions)
The speed reduction rate at the time of a collision is calculated for every test.

$$\text{The speed reduction rate} = \frac{\Delta V_0 - \Delta V_C}{\Delta V_0}$$

Vo: Initial relative velocity, Vc : relative velocity in case of collision is able to be avoided at the time of a collision, a speed reduction rate is set to "1."

4. Allocation of marks(points)
32 points are assigned about AEBS (car to car) according to the accident reduction
Calculated the reduction effect by a system functioning in death and a serious injury accident. An alarm function and a control facility is 1:1



Score points based on effect

condition	The reduction number of deaths and seriously injured per year	The effect of reducing the social loss (Evaluation points)
total	3,968	100
car to car	1,708	33
car to pedestrian	2,260	67

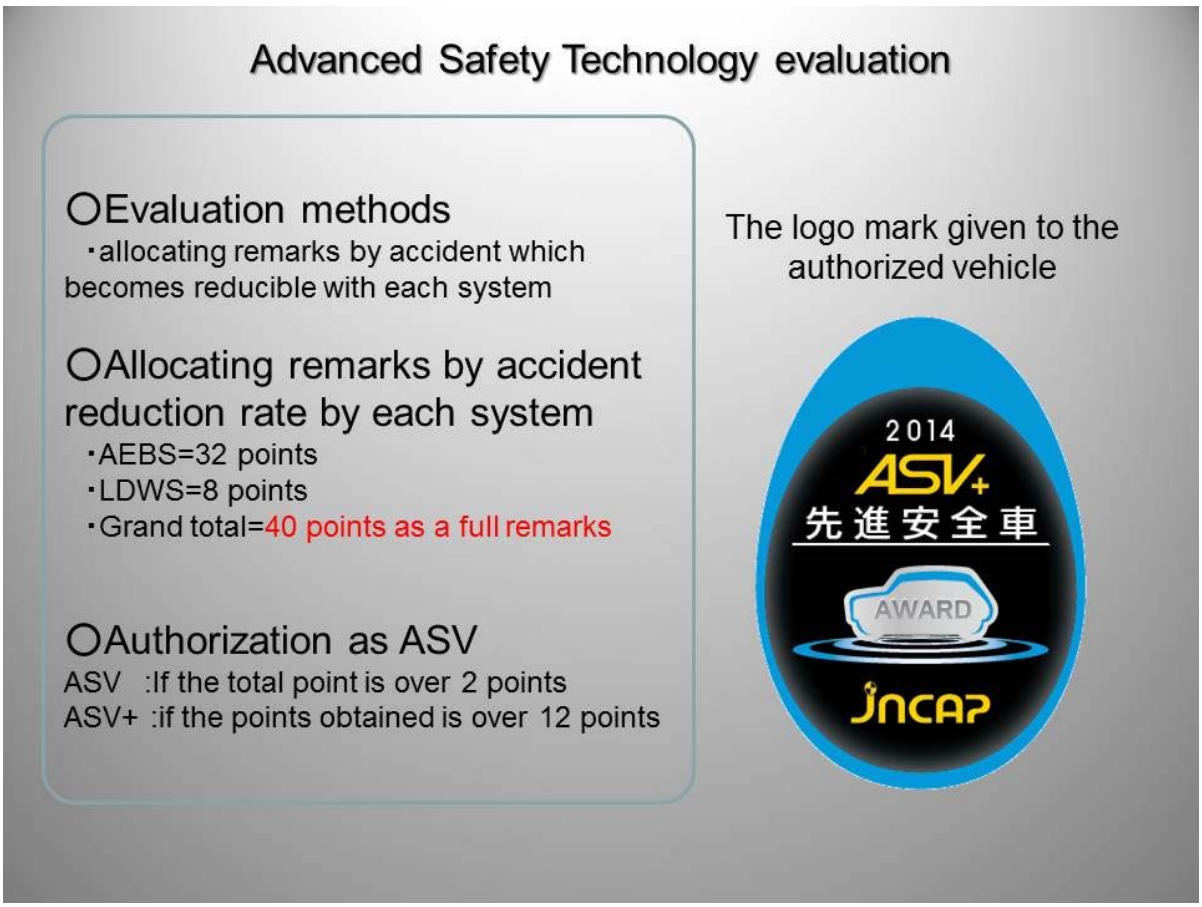
For safety reason of test, 32 points are assigned instead of 33

2) Test procedures and evaluation methods for LDWS

We referred to US NCAP's test procedure and modified the evaluating methods for meeting a real Japanese accident condition. To be concrete, audible or visual; more than two different alert at a time should be confirmed in the test area when test vehicle runs with constant lateral velocity at 60km/h or 70km/h when approaching the lane line. This is repeated five times for both sides. Points should be calculated with the evaluation methods same as AEBS test. 8 points is given when it has started appropriately with velocity at 60km/h that is forecasted from the reduction effects of accidents.

4. Publishing policy of advanced safety technology assessment

The publication of the advanced safety technology assessment is held separately from other results of the assessments with the respect of enhancing its spread. We use a logo mark for exclusive use to gain more public interests.



Moreover, we implement public relation activities including distribution of comprehensive leaflets and more than 500 thousands leaflets distributed among each manufacture's sales points. And logo mark stickers are indicated on their models.

5. The results of advanced safety assessment in fiscal year of **2014**

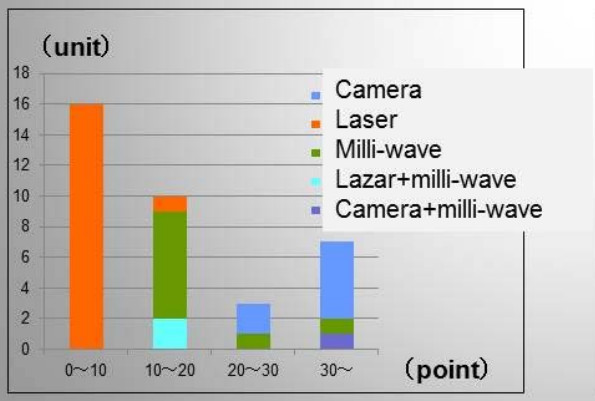
In fiscal year of 2014, we had 37 models tested as many devices are spreading rapidly to the market and it becomes competitive. As a result, all models had a definite safety performance. On the other hand, each of the technology which was used in AEBS had different characteristics and detection system to different speed range. We have found two characteristics; 1. AEBS using lazar radar mainly used in reasonable compact cars such as kei-cars, are spreading well. 2. AEBS using milli-wave or camera functioning well at middle speed range. This category aims at a higher level of safety. Combination with FCWS and assist braking system, combination of multi detectors, image detecting system with high resolution and coloring dual camera raises more safety. Considering the tests have many aspects in speeds and scenarios making a valiant effort should be important for stable controls and indispensable for forthcoming AEBS (car to pedestrian) tests. I believe that many manufacturers and suppliers cooporate to develop these technologies.

AEBS Test result

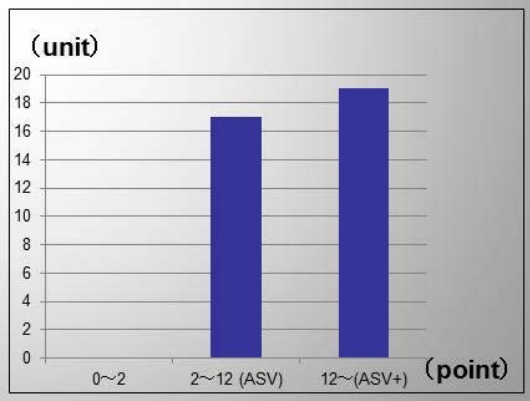
• Device features

Device	Feature
Millimeter-wave Radar	-detects the position of person or running vehicle, speed, and relative speed by irradiating a short wavelength radio wave -detection distance is relatively long
Laser Radar	-detect the distance to the obstacle based on the reflection from the device -detection distance is relatively short
Camera	-detect obstacles by analyzing the images

• Unit/AEBS points



• Unit/ASV points



6. Forthcoming events

We are implementing for introduction of rear view monitoring test in fiscal year of 2015 and AEBS (car to pedestrian) tests and evaluations in fiscal year of 2016 in respect of needs from end users and victims of the traffic accident according to our roadmap. We have already started after setting up procedures and evaluation methods for around view camera with the research on accident data and simulations. Also for AEBS (car to pedestrian) tests, we need to determine procedures and evaluation methods with the making of test scenarios meeting real accident data and allocation of the points based on the reduction effects of accidents in 2015. Having been considering Japan's present circumstances, it is the key issue how we can focus to link with the assessment with increasing number of accidents that is often very severely involved by elderly people and accidents at night. We have been discussing many points at Task Force and Working Group under JNCAP steering committee.

7. Conclusion

We will have 30 to 40 models be tested in fiscal year of 2015 as manufactures became conscious of putting safer and innovative technology on the market. We need to maintain this trend continuously. NCAP operation bears a big power on its cooperation with the Japanese nation, industries, government and academics. And end users and manufactures need to take the results of NCAP assessments seriously moer than ever before. For those accounts we need more substantial work on test procedures and evaluation methods, also we regard international cooperation important to share experience and knowledge.