# Bertil Aldman Award Lecture

# Saving Lives with Safer Cars: The Past, Present and Future of Consumer Safety Ratings

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***Abstract*** The 2016 Bertil Altman lecture provides a historical perspective on the development of consumer safety ratings and gives an overview of the tests carried out by many New Car Assessment Programs around the world. It presents the latest challenges and identifies future research needs in this area.

***Keywords*** New Car Assessment Program, Consumer Ratings, Crash Avoidance, Automated Driving.

## I. INTRODUCTION

In April 2016 the United Nations General Assembly adopted a new resolution calling for "Policies and measures to implement United Nations vehicle safety regulations or equivalent national standards to ensure that all new motor vehicles meet applicable minimum regulations for occupant and other road users' protection, with seat belts, air bags and active safety systems as standard" [1]. This resolution is the strongest-ever global commitment on road safety and is a significant milestone in the bid to curb the number of people killed and injured on our roads. In its message, there is a strong recognition that vehicle safety technologies will play a role in eventually eliminating death and serious injuries from our roads. The United Nations General Assembly resolution also reminds us that access to safe vehicles is a fundamental consumer right.

Over the last decades, consumer demand for safer cars has served as a catalyst to car manufacturers and governments to improve vehicle safety standards throughout the world. In 1979, the National Highway Traffic Safety Administration (NHTSA) launched the New Car Assessment Program (US NCAP) to provide information to consumers on the relative crashworthiness of automobiles [2]. The outcome, the first public safety ratings for cars, mobilized consumers and enabled them to make a more intelligent, better informed buying decision based on a car's crash test performance. This in turn incentivized vehicle manufacturers to innovate and provide safer vehicles at lower prices to attract customers.

The success of NHTSA's first safety ratings has since inspired other regions and organizations to develop their own vehicle assessment programs, based on the same formula. Over the last 25 years, no fewer than 10 official programs have emerged around the world, covering high income markets such as Japan [3], the Republic of Korea, Australia [4] and Europe [5], and upper and lower middle income markets like China, Latin America [6] and South-East Asia [7]. And while new rating initiatives are being launched in India in parallel to (and to expedite) the introduction of minimum vehicle safety standards [8], high-tech upgrades to US NCAP have been announced by NHTSA that include a new crash test, more biofidelic dummies, and crash-avoidance ratings [9]. The level of engagement worldwide and the activity that is still visible today underlines the important role of vehicle safety ratings to many regional road safety policies and demonstrates that the NCAP approach can be successfully applied to countries with very diverse market conditions and vehicle fleets.

The European New Car Assessment Program (Euro NCAP) was established in 1997 with the aim to provide motoring consumers with a realistic and objective assessment of the safety performance of the most popular cars sold in the European Union. Euro NCAP is a public-private partnership which operates independently from the European type approval system. At present, the organization has 12 members including the Member State governments of the United Kingdom, Germany, France, Sweden, the Netherlands, Luxemburg and the regional government of Catalonia; the International Automobile Federation FIA; motoring clubs ADAC and ACI; Consumers International; and Thatcham Research, primarily focussed on the needs of the motor insurance industry [10]. Among all NCAPs, Euro NCAP is considered one of the better established programs and Euro NCAP's test and assessment protocols are often referenced by other NCAP programs.

## II. THE EVOLUTION OF CRASH RATINGS

***Crash testing for frontal collisions***

The roots of many consumer rating programs can be found in regional vehicle crash test legislation. This means that a compliance crash test has been adopted but altered in order to motivate manufacturers to optimize safety performance beyond the minimum legal requirements. To this extent, most NCAP programs have begun testing in front impact (full width and/or offset) conditions using Hybrid-III adult crash test dummies to assess the injury risk. For example, US NCAP's first full-width front barrier test was derived from FMVSS No. 208 but executed at higher severity compared to the compliance test, in order to raise intrusion and acceleration levels in the occupant compartment [2]. Similarly, Australasia NCAP, Euro NCAP and others adopted the off-set deformable barrier test at a higher impact speed than regulation, alone or in addition to the full-width test. In most instances, the biomechanical injury criteria (HIC, chest accelerations etc.) are not unlike those applied for compliance testing, yet often more demanding limits or additional requirements are set. As a result a car which barely meets legal requirements is likely to be limited to a one or zero star rating by NCAP.

The above approach of basing consumer ratings on compliance testing has allowed standards in occupant protection to evolve at a fast pace. In Europe, the start of Euro NCAP testing coincided with the full implementation date of directives for frontal and side vehicle impact (96/79/EC and 96/27/EC, respectively). From 1997 onwards, new batches of test results were published about twice each year and car manufacturers, setting aside their initial reservations, started to sponsor the testing of their own cars. As new car models replaced those already tested, the improvements in occupant protection over and beyond the legal requirements could be clearly observed [5]. Following the success of the first 5 star rating for the Renault Laguna in 2001, manufacturers increasingly saw this as the goal for all their new models for the EU market.

However, success doesn't always come easy. Latin America is one of the world worst performing regions with an annual road fatality rate of 17 deaths per 100,000 individuals, almost double the average rate registered for high income countries [8]. When Latin NCAP was launched in South America in 2010, many models fell short of meeting frontal impact test requirements, despite the fact that many of the manufacturers routinely achieved 5 stars in Europe and elsewhere — often for models with the same name. Six years on, visible progress has been made but zero star results are still no exception (Figure 1). The program is still waiting to see the broad industry engagement that is needed to improve vehicle safety as the governments responsible have so far been unable to agree on realistic minimum safety requirements for the region. This underlines the fact that the NCAP formula works best to complement compliance testing and neither can nor should not replace it.

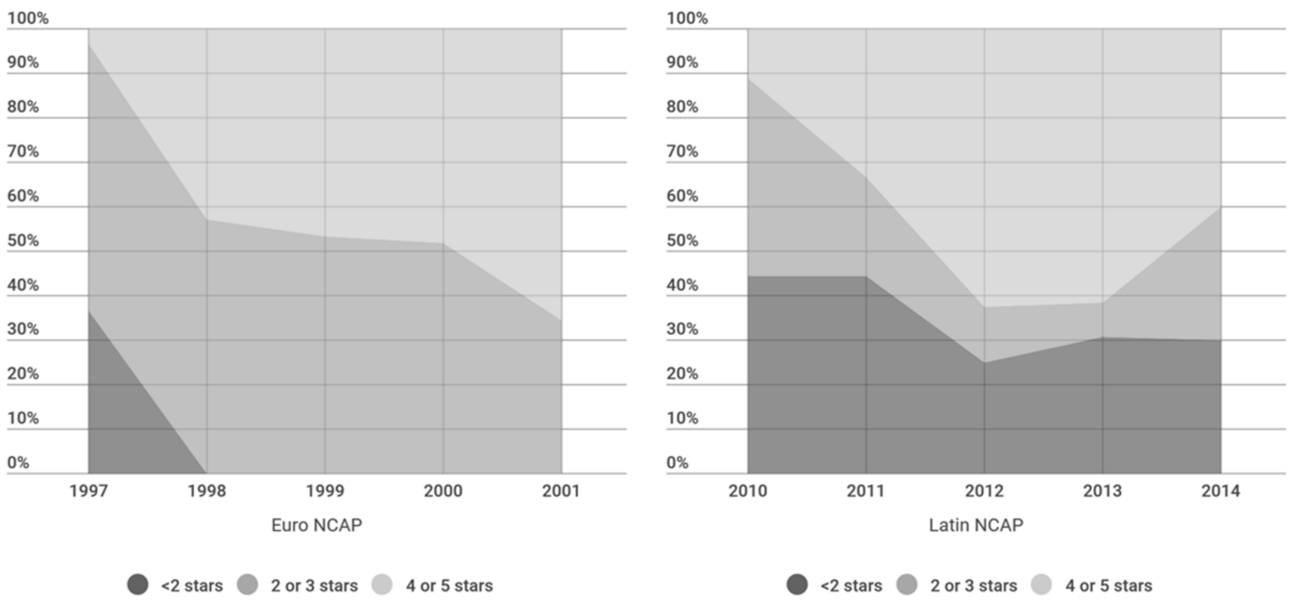


Fig. 1. The annual share of cars that was awarded either 4-5 stars, 2-3 stars or less. Evolution of ratings in first five years of Euro NCAP (1997-2001) versus Latin NCAP (2010-2014).

***NCAP expansion***

As cars became increasingly better in frontal crash performance, opportunities for improving vehicle safety further were considered. The different objectives, markets and priorities of the various consumer rating programs led to the development of a multitude of new tests that found their way into one or more assessment of the schemes during the last two decades (see Appendix I).

*Side impact crashes*

Side crashes account for about a quarter of passenger vehicle occupant fatalities and a more sizeable 40 percent of serious injury crashes. In the mid nineties, vehicle makers started to install side airbags and strengthen the structures of vehicles to prevent ejection and provide a survivable occupant environment. Around the same time, moving deformable barrier and side pole crash tests were introduced in consumer rating programs to verify the effectiveness of these measures, to drive improved installation rates and promote further innovations.

NHTSA began testing passenger cars in side impact in NCAP in 1997. The US NCAP side impact — a 90 degree side impact in which a moving deformable barrier, crabbed at 27 degrees, strikes a stationary vehicle — is taken from FMVSS 214 but run at approximately 62km/h, 8km/h higher speed than in the compliance test. In Europe, Australia and Asia, side impact barrier tests are also performed but follow the perpendicular (non-crabbed) test configuration of the UN/ECE standard at speeds ranging from 50 to 55km/h. However, as head impact does not regularly occur in the barrier test, some have adopted an additional pole test to assess the benefit of head protecting airbags for side impact. In the US, the Institute for Highway Safety (IIHS) was concerned that these tests still didn't completely capture the types of crashes likely to occur in the real world with SUVs and pickups. In 2003 the institute initiated its own test with a different barrier — one with the height and shape of the front end of a typical SUV — and a new small female dummy, SID-IIs [11].

Since then, the various tests underpinning the side impact crash ratings around the world have continued to evolve. More recent developments include the application of an oblique pole test by US NCAP and Euro NCAP amongst others; the adoption of the advanced WorldSID mid-sized male dummy [12]; the AE-MDB barrier [13]; and an assessment of the head protection device extended to rear seats by JNCAP and Euro NCAP.

It is clear that the focus on improving side impact protection has delivered real benefits. IIHS estimated that the overall effectiveness of side impact protection measures, particularly side airbags and curtains, at 45 percent fatality reduction for drivers of cars with head-protecting side airbags, and 11 percent reduction with torso-only side airbags [14]. Folksam and Chalmers also reported a significant reduction in the injury risk in side impact for near-side occupants in a more recent study [15].

*Pedestrian crashes*

According to the WHO, over a third of road traffic deaths in low- and middle-income countries are among vulnerable road users [16]. In high income countries, pedestrian motor vehicle crash fatalities have decreased over the last decades but still account for 15 to 20 percent of crash deaths. The pedestrian protection subsystem tests developed and validated by EEVC [17] have been the basis for testing and assessment protocols by Euro NCAP, Australasian NCAP, Japan NCAP and others. Over the years, the test procedures have seen various updates and the adoption of more biofidelic test devices, such as the JARI Flex PLI [18]. With a vehicle industry that has resisted expensive engineering solutions, however, the changes in car front-ends have been slow to emerge. In 2009, Euro NCAP addressed this by introducing a new rating system that required minimum performance in pedestrian protection in order to achieve an overall star rating. The proportion of vehicles achieving good pedestrian scores has noticeably improved in recent years.

The inclusion of pedestrian subsystem testing in consumer ratings has brought about more pedestrian-friendly designs and has triggered new innovations such as "pop-up" bonnet technology. A significant correlation between (Euro NCAP) pedestrian subsystem scores and injury outcome was reported by Pastor using German National Accident Records from 2009 to 2011 [19]. Comparing a vehicle scoring 5 points and a vehicle scoring 22 points, pedestrians' conditional probability of getting fatally injured was reduced by 35 percent (from 0.58 to 0.37 percent) for the latter. Strandroth et al. [20] also showed a significant reduction of injury severity for cars with better pedestrian scoring. The reduction of Risk of Serious Consequences (RSC) for medium performing cars in comparison with low performing cars was 17, 26 and 38 percent for 1, 5 and 10 percent of medical impairment, respectively. These results applied only to urban areas with speed limits up to 50km/h.

*Roll-over crashes*

The 1990s and early-2000s saw the sales of Sport Utility Vehicles (SUV) and pick-up trucks surge in the North America and Australia. Inherently, these vehicles have a greater risk of rolling over and, with such crashes causing some 10,000 fatalities annually in the United States by the start of the new millennium, it wasn't long before this accident type became a key priority. In 2001, NHTSA added a new test for rollover resistance assessment to their rating system using a "Static Stability Factor" (SSF), based on a vehicle's measured static properties. The NCAP rollover resistance rating was later amended to include the results of a dynamic vehicle test in addition to the SSF but also the results of a dynamic vehicle test [2]. In 2009, the IIHS began testing the roof strength of vehicles, to ensure that the roof can maintain the occupant survival space when it hits the ground during a rollover [21].

Today, consumer information on rollover resistance remains largely a North American phenomenon. A notable exception is Korean NCAP which adopted the dynamic roll-over assessment in 2004 and now publishes a Driving Stability Rating based on roll-over and braking tests [22]. Another effective countermeasure for rollovers, especially fatal single-vehicle ones, is Electronic Stability Control (ESC). Installation of ESC equipment was successfully promoted in various rating schemes, such as Australasian NCAP, US NCAP and Euro NCAP, before it became mandatory for all passenger cars and light trucks in their respective markets. ESC remains an important condition for 5 stars in Latin and ASEAN NCAP, where this technology is still not mandated.

*Whiplash neck injury*

Whiplash-associated disorder remains the most frequently reported injury in insurance claims across many high income countries. As whiplash injury to the neck often leads to long term impairment, with 10 percent of people suffering long term discomfort and 1 percent permanent disability, addressing "whiplash" injuries, their causes and prevention has been an important priority for the auto insurance industry and governmental bodies.

Whiplash may occur in all impact directions but the injury is most frequently observed, and its risk most effectively addressed, in rear-ends impacts. For this injury type, no biomechanically based vehicle safety regulations exist, mainly as a consequence of the limited (or inconclusive) knowledge available on whiplash. However, research has demonstrated that, in the event of a rear-end collision, the vehicle seat and head restraint are the principal means of reducing neck injury [23].

Starting from the assumption that lowering loads on the neck lessens the likelihood of whiplash injury, the first stand-alone tests for seats and head restraints were developed by the International Insurance Whiplash Prevention Group (IIWPG) [24] and the Swedish Road Administration (SRA) [25]. However, the tests adopted different philosophies with regards to relevant seat performance parameters, one putting heavy emphasis on real world validation (IIWPG), the other using plausible hypotheses regarding the causes of whiplash injury (SRA).

The IIHS has been publishing ratings of head restraint geometry since 1995 and has been rating head restraint systems since 2004 using a combination of their static measurement procedure and the IIWPG developed "single-pulse" dynamic sled test procedure. Australasian NCAP began publishing head restraint geometry ratings to the IIWPG protocol in 1997 and added the dynamic test in 2012. China NCAP and Korean NCAP adopted a dynamic test based on the IIPWG pulse around that same period. In 2008, Euro NCAP launched the first series of results of (front) seat testing based on its own geometric and "three pulses" dynamic sled test procedure, which combined aspects of both the IIWPG and SRA method [26]. In 2014, the geometric assessment procedure was extended to include rear seats. Japan NCAP has conducted similar assessments of vehicles in Japan using other injury criteria and pulses starting 2010 [27].

Kullgren et al. [28] carried out an evaluation of the Euro NCAP, Japan NCAP and IIWPG whiplash protocols using real-world crash data. Three analyses were undertaken comprising an analysis of test outcome data, a logistic regression analysis, a receiver operating characteristic (ROC) analysis, and a correlation analysis comparing crash and injury outcome. Correlations between the test scenarios of each of the three protocols - as well as the outcome associations with crash outcomes - suggested consistent improvements in the risk of permanent medical impairment.

*Child occupant protection*

Many high and middle income countries require the use of child safety seats for infants and children, fitting specific criteria for certain age or size groups, even though the exact requirements in each country, region or state may vary considerably. Child fatalities in motor vehicle crashes have steadily declined over the last decades thanks to these laws and better consumer information. However, vehicle crashes remain a leading cause of death and disability for children and young adults today.

For many years, automobile manufacturers have relied on the suppliers of child restraints to ensure protection for children in cars. However, there are many aspects of child protection which cannot be influenced by the child restraint manufacturer alone but which require action on the part of the car manufacturer as well.

In 2003, Euro NCAP introduced a child occupant star rating, specifically addressing the protection of children in the event of a crash. The rating was based on the protection offered in the front and side crash tests to a three year old and 18 month old child seated on the rear seat in a restraint of the type recommended by the car manufacturer. The assessment was complemented with other incentives with regards to communication (handbook instructions, information at dealerships, warning labels, etc.), an assessment of the ease of child seat installation and availability of easy-to-use ISOFIX attachments and other relevant equipment, such as a front passenger airbag deactivation switch. Between 2013 and 2016, Euro NCAP introduced several updates to the child occupant assessment rating including a Child Restraint System (CRS) Installation check, new incentives for *iSize* compliant seating positions and the use of Q6 and Q10 child dummies in crash tests [29].

Among all NCAP programs, a similar assessment of child safety, based on 2 different child dummy seated in child restraint systems and additional criteria is being used only by ASEAN and Latin NCAP at the moment. China NCAP introduced child safety assessment in full frontal 50km/h rigid barrier test from 2010 [30]. For the China NCAP 50km/h full-with test, a P3 child dummy is positioned in the vehicle outboard rear seat, but in the opposite side a Hybrid III 5%ile female dummy is positioned. The IIHS does not use child dummies in their front and side crash testing — a small adult female dummy, comparable in size to a 10 year old child, is placed on the rear seat for the side impact test — but its LATCH ratings [31] are an indicator of how easy it is to achieve a correct, tight installation of a child restraint in a given vehicle when using the dedicated child restraint attachment hardware. Australasian NCAP uses child dummies in the test but does not use the results to assess child protection, because there is a separate consumer testing program for child restraints in Australia [4].

*Intelligent seat belt reminders*

As protection for belt wearers improved, accident data increasingly showed that a higher proportion of seriously and fatally injured casualties were not wearing their seat belts [32]. To improve this situation, Euro NCAP first developed a protocol to encourage the fitment of Intelligent Seat Belt Reminders (SBR). Research had shown that most non-wearers could be persuaded to use their seat belt if they were given a suitable reminder. Although simple reminders have been available for many years, intelligent systems can be much more effective: almost unnoticed by belt wearers but increasingly aggressive and demanding for those who do not “buckle up.”

For front seats, Euro NCAP requires a “final signal”, which has to be audio-visual and must be presented at the latest 60 seconds after the engine start, after 500 meters of vehicle travel or speeds above 25km/h. The final signal must last for a minimum of 90 seconds and consist of a “loud and clear” audible signal and a visual indicator. For rear seats, Euro NCAP requires a “start signal”, which may be visual only. For all seats, if a change in belt status occurs at speeds above 25km/h, i.e. a belt gets unbuckled, an immediate audible signal must be given. The Euro NCAP protocol recommends occupant detection on the rear seats, but does not require it.

Since 2003 Euro NCAP and Australasian NCAP rating systems have encouraged front and rear SBR by awarding points that count towards the overall score or, more recently, the Safety Assist component of the rating system. Most light vehicles in these regions now have SBR for all seats. This excellent outcome has been achieved in the absence of any regulation to require SBRs.

When Japan NCAP introduced an overall rating scheme in 2011, SBR points became part of the evaluation

[27]. It also includes a reward for advanced seat belt reminders on the rear seats: additional points can be scored if the rear SBR alert includes an audible warning of at least 30 seconds. Such a warning, however, can only be triggered if passenger presence information is available [33]. Many other NCAPs, such as Korean, China, ASEAN and Latin NCAP have included incentives for the SBR systems into their rating.

Lie et al. [34] conducted an extensive study into the effect of enhanced SBR in six European countries. This study concludes that seat belt reminders fulfilling Euro NCAP's SBR protocol significantly increase seat belt use in daily traffic: around 80 percent (82.2 ± 8.6) of drivers not wearing a belt in cars with no seat belt reminder do so in cars equipped with a system that has a visual signal and an associated loud and clear sound signal.

*Small overlap and front oblique crashes*

Small overlap frontal crashes primarily affect a vehicle's outer edges, which aren't well protected by the traditional crush-zone structures. To help drive further improvements in frontal crash protection, the IIHS in 2012 introduced a small overlap (SO) frontal crash test [35]. The SO test is foremost a test that drives structural countermeasures although it may also be a challenge for some belt restraint and airbag designs because of the higher oblique loading component. According to the IIHS, three main strategies (that are often combined) have emerged for improving protection in IIHS small overlap front tests: strengthening the occupant compartment, adding new structures to engage the barrier and creating an additional load path for crash forces (Figure 2). As such, the small overlap test has the potential of adding weight to vehicle. This negative effect is expected to reduce as improved designs are developed, but in the meantime Euro NCAP and other programs continue to explore alternative approaches to reducing narrow overlap crashes on the basis of crash avoidance technology.

Frontal crashes remain the most common type of crash resulting in fatalities and therefore developments in crash testing are expected to continue. One notable future upgrade will be the use of the advanced THOR-M anthropometric test device and biomechanical injury criteria in two new test procedures: in US NCAP’s moving deformable barrier (OMDB) test procedure for evaluating small overlap and oblique crashes [9] and Euro NCAP’s mobile progressive deformable barrier (MPDB) test for vehicle compatibility evaluation [36].

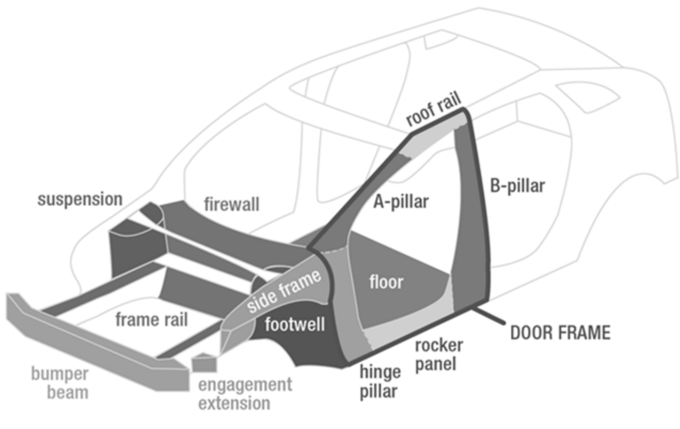


Fig. 2. Areas modified for small overlap performance. *Not pictured: door beam, seat mount, wheel, steering column.* Source: Insurance Institute for Highway Safety. Status Report, Vol. 49, No. 11, December 23, 2014.

## III. THE ADVENT OF CRASH AVOIDANCE

By the mid-2000’s, crashworthiness ratings had been in common use around the world for a decade or more and the industry's efforts to deliver increasingly safer cars had resulted in many 5 stars successes. But while this represented a significant step forwards for consumer protection, concerns started to rise over the future direction and the message that the programs continued to deliver.

The key cause behind these concerns was the emergence on the market of a new category of safety technologies designed to automatically intervene in critical, near-crash situations and assist the driver in driving safely (Advanced Driver Assistance Systems, ADAS). Several car manufacturers have made their commitment to active safety clear, among them Daimler, but also Volvo, which was amongst the first to offer a collision mitigation system as a standard installation in a consumer vehicle. Yet, avoidance and ADAS technology was largely overlooked by consumer rating programs at this time (with the exception of Electronic Stability Control, which was encouraged by several NCAPs in the late 2000s).

The industry's shift from passive to active safety initially put the NCAPs on the backfoot as they grappled with the wide variety of new systems and functionalities entering the market and the lack of suitable, "regulation-quality" performance tests for these new systems. To make matters worse, only a few systems were offered as standard and the uptake of optional systems in the fleet was generally low. This seriously challenged the ability of NCAPs to quickly identify and confirm (from real world data) those technologies that delivered a true benefit to the consumer and to society. Consequently, the risk grew that the ratings were becoming less relevant and influential.

*Autonomous Emergency Braking*

Autonomous Emergency Braking (AEB) is without doubt the most important active safety technology that has emerged since ESC. Using sensors such as radar, lasers and cameras to identify other vehicles or other road users, AEB automatically applies the brakes if the driver does not respond in time, to avoid or mitigate a collision, saving countless lives, injuries and inconvenience. Systems are most effective at lower speeds (<40km/h) where more than 75 percent of rear-end crashes occur, but they are also valuable in mitigating the devastating effects of higher speed crashes by reducing impact speeds, if a crash cannot be avoided.

AEB, or Crash Imminent Braking (CIB) as it is referred to in the US, was one of the technologies covered under the Crash Avoidance Metrics Partnership (CAMP) [37] between NHTSA and the American auto industry. CAMP was established in the mid-nineties to accelerate the implementation of crash avoidance countermeasures in passenger cars. Based on the ground work by CAMP and their own research activities, NHTSA began recommending Forward Collision Warning (FCW) systems to consumers starting with the 2011 model year. NHTSA recently announced that it would include AEB systems (crash imminent braking and dynamic brake support) as a recommended technology and test such systems starting with model year 2018 vehicles [38].

Within Europe, four main initiatives have actively contributed to development of test procedures for assessing AEB and forward collision warning systems for car-to-car crashes. ADAC, with support from automotive suppliers Continental and Bosch, developed an inflatable vehicle target [39] in order to perform a comparative test of AEB systems on high-end vehicles. The RCAR Autonomous Emergency Braking group [40], led by Thatcham Research, designed a testing and (insurance) rating approach for AEB systems. The European Commission sponsored research project ASSESS (Assessment of Integrated Vehicle Safety Systems for improved vehicle safety) [41] and the German initiative led by DEKRA, called Advanced Forward-Looking Safety Systems (vFSS) [42] had similar project goals to develop harmonized and standardized assessment procedures and related tools for selected integrated safety systems. Based on the outcome of these research projects, Euro NCAP adopted both low speed and high speed AEB systems in the rating scheme in 2014. In 2016, the first AEB Pedestrian test was added to provide an incentive for systems with advanced detection capabilities [43].

The low speed "AEB City" test also became an RCAR standard and in essence is the same as the Insurance Institute for Highway Safety Autonomous Emergency Braking Test. China NCAP is expected to include their AEB test protocol in its suite of tests beginning from 2018 and Australasian NCAP will align with Euro NCAP for AEB and other tests in the same year.

The IIHS states that (low speed) "AEB systems can reduce auto insurance injury claims by as much as 35 percent" [44]. Euro NCAP, with support of the Australasian NCAP, studied the effectiveness of the low speed AEB systems promoted through the rating scheme since 2014, and showed that low speed AEB technology leads to a 38 percent reduction in real-world rear-end crashes, with no significant difference between urban and rural crash benefits [45].

*Lane Support Systems*

Lane support technologies, such as Lane Departure Warning and Lane Keep Assist, are designed to address single-vehicle run-off-road and head-on crashes. The IIHS [46], NHTSA [47] and others [48] have studied the potential of these crash avoidance technologies and have estimated big potential fatal crash reductions. However, current lane support systems often are poorly accepted by consumers, mainly because warning systems are perceived as annoying and unreliable. Evidence that lane support technology is delivering on its promise has so far been lacking, but some positive indications have recently started to emerge from field data in Sweden [49].

To improve the performance of these systems, US NCAP and Euro NCAP have introduced incentives as part of their respective consumer rating programs. The technology is tested in a fairly straightforward manner by steering the LDW or LKA equipped vehicle slowly towards a solid or dashed line, thus triggering a warning or intervention [47]. While NHTSA's test can be performed by a driver, Euro NCAP's test protocol requires path accuracy that can only be performed by driving robots that can also be used for AEB testing.

More intuitive, intelligent and integrated systems are expected to emerge in the coming years that will be able to avoid unintended road departures, critical lane change maneuvers as well as (narrow off-set) head-on collisions. The NCAP test protocols are expected to evolve to take account of these developments.

*Speed Assistance Systems*

Excessive speed is a factor in the causation and severity of many road crashes. In fact, it has a greater effect on the number of accidents and injury severity than almost all other known risk factors. Speed restrictions are intended to promote safe operation of the road network by keeping traffic speeds below the maximum that is appropriate for a given traffic environment. Voluntary speed assistance systems (SAS) are a means to assist drivers to adhere to speed limits, by warning and/or effectively limiting the speed of the vehicle. The only technical requirements for such devices are laid down in United Nations Regulation No. 89 "Speed Limitation Devices", which is not mandatory in Europe and does not specifically apply to M1 passenger cars.

Starting from 2009, Euro NCAP has rewarded manually set and driver advised speed limitation devices which meet the basic requirements of United Nations Regulation No. 89 but have additional functionality with regards to the warnings given and the ability to be set-at-speed. By doing so, Euro NCAP has created a first incentive to manufacturers to promote such speed-limitation devices, to make them available on more models and to fit them as standard equipment [50]. Around 90% of vehicles achieving a 5-star rating from Euro NCAP in recent years have a speed-limitation device, usually in combination with a cruise control system. Recently, more advanced speed assistance systems have been introduced onto the market which are able to inform the driver of the speed limit at the vehicle's current position, based on digital speed maps and/or traffic sign recognition. The Euro NCAP rating system also encourages these speed limit information functions (SLIF). Although there are still limitations to these technologies, intelligent speed assistance systems that combine speed limit information and (over-rideable) speed-limitation, have much greater potential and will be more readily acceptable to the public. As a result, Euro NCAP extended the speed assistance protocol in 2013 to include the latest generation of intelligent speed assistance systems, while Australasian NCAP has considered it an optional Safety Assist Technology since 2011.

***Combining passive and active safety***

Different NCAPs have dealt differently with the situation of emerging advanced technology in their respective rating systems. In US NCAP, vehicles earn ratings of 1 to 5 stars in frontal crash and side crash performance, as well as in rollover resistance. Since 2011, vehicles also earn an Overall Vehicle Score rating, which indicates how the individual 5-Star Safety Ratings combine to reflect a vehicle's overall safety. NHTSA has utilized NCAP to encourage automakers to add advanced safety features on a voluntary basis and recently began evaluating which ADAS technologies might potentially be included in the near future. Today the US NCAP checklist includes forward collision warning, lane departure warning and backup cameras (followed by Autonomous Emergency Braking technology as of MY 2018 models). The checklist gives consumers a quick and easy way to compare the availability of safety features across models although fitment does not affect the star rating.

In 2009, Euro NCAP changed from three individual crash ratings to a single overall safety rating with a maximum of 5 stars. This overall rating combined the results of assessments in four areas: adult protection, child protection, pedestrian protection and the new area of safety assist technology. The underlying tests included the full-scale frontal offset, side-impact barrier and pole tests carried over from the previous adult and child protection ratings, the seat tests for whiplash prevention in rear-end crashes and front-end component tests for pedestrian protection. The assessment of Intelligent Seat Belt Reminders was complemented with that of Speed Assistance Systems and Electronic Stability Control as part of Safety Assist. In each area of assessment, scores were calculated as a percentage of the maximum points available and a weighted sum of these scores indicated the car's overall all-round performance. The testing of low and high speed Autonomous Emergency

Braking as well as Lane Support systems was added in 2014. The latest update of the Euro NCAP rating is the addition of Autonomous Emergency Braking technology for Pedestrians.

Other NCAPs responded with changes to the rating systems, which sit in between the “encompass all” approach of Euro NCAP and the advisory approach of US NCAP. For example, to qualify for IIHS’s Top Safety Pick, a vehicle must earn good ratings in five crashworthiness tests — small overlap front, moderate overlap front, side, roof strength and head restraints — as well as a basic rating for front crash prevention, its low speed Autonomous Emergency Braking technology test. To qualify for Top Safety Pick+, a vehicle must earn good ratings in the five crashworthiness tests and an advanced or superior rating for front crash prevention. Australasian NCAP star rating is based on the vehicle’s performance in frontal off-set, side barrier and pole crash tests, as well as pedestrian and whiplash tests. To earn 5 stars, it also requires key features such as SBR on front and rear fixed seats, head protecting technology (curtain bags) for front and rear seat, 3-point seat belts for all forward facing seats and ESC. This scheme was extended with a “tick-box” approach, based on a menu of Safety Assist Technologies (referred to as “additional SAT”), that includes many potential technologies, but does not require any functional assessment.

It is likely that we will see several major NCAP program changes in the near future in relation to avoidance system testing. In its latest notice [9] NHTSA has announced a new approach to determining a vehicle’s overall 5-star rating that will, for the first time, incorporate advanced crash avoidance technology features, along with ratings for crashworthiness and pedestrian protection. Australasian NCAP has announced their full alignment with Euro NCAP rating regime in 2018, the same year that China NCAP is planning to begin AEB testing as part of their star rating. Other NCAPs like Korean Japan NCAP have moved to an overall rating system or are in the process of making changes to accommodate crash avoidance technologies.

## IV. THE FUTURE OF AUTOMOTIVE SAFETY

***Market Challenges***

In developed markets, new cars today are much safer than they were a decade ago thanks to improved crash test standards, crumple zones, seatbelts and airbags, which all help to protect occupants in a crash. While most occupant safety measures can be considered mature, more could and should be done to improve their robustness and effectiveness for the general diversity of vehicle occupants and crash scenarios. This is particularly true for an aging or obese driving population and angled and multi-vehicle crashes. A major challenge remains in developing markets that are showing extraordinary growth in the number of vehicles in use.

Crash avoidance systems can help prevent accidents from happening in the first place. Considering the time any new technology needs to penetrate the vehicle fleet, it is important that they are effectively deployed to address the above key accident scenarios, including those that involve other road users and commercial vehicles. Today, the uptake of crash avoidance technology still poses a particular challenge: a large variety of systems is available but only a few are offered as standard. The uptake of optional systems is still low and depends greatly on market incentives. The situation is likely to improve as the need for more on-board technologies to support (partial) automated driving will make crash avoidance systems cheaper and more cost-effective across the car fleet. Voluntary agreements to make equipment standard across the fleet — like those recently announced by US.DOT and IIHS on AEB systems in the USA [44] — greatly help generate the momentum in the market place.

Besides the price, the acceptance and volume of advanced technologies are driven largely by how well consumers understand these features and value them. For this, the vehicle rating must reflect the true contribution of passive and active safety measures to the overall safety performance. The lack of traceability of (the performance of) systems in the market, the complex role of driver behavior and inconsistency in Information, Warning and Intervention strategies across the industry, all further complicate the important task of identifying the true potential of avoidance technology.

***Automated Driving and Cooperative Safety***

The idea of automated driving and self-driving cars has been widely aired in technical discussions and in media coverage recently. The rapid development of electronic safety systems and communication over the air has made the concept possible and the first cars have come onto the market, which are able to “drive” in controlled situations. The established vehicle industry is active in this field but new players such as Google have also shown self-driving prototypes. There is no doubt that greater automation will lead to a revolution in safety, putting it above all other requirements and characteristics of a car. Not only will the self-driving car have the technology to sense, avoid and mitigate in potential crash scenarios, it will also drive in a safer manner. Besides that, used in a manual way, the vehicle will always carry the safety elements and technologies to intervene when necessary.

However, as Volvo, Mercedes, Tesla, GM and others are launching their first auto-pilot, highway driving assistant systems, it is not easy to see how safety may be significantly (or even positively) affected in the short term. Cars with increasing levels of automation will allow drivers to delegate control, taking their eyes of the road and engage in activities unrelated to driving. Drivers, however, have to resume control in conditions not yet supported, such as adverse weather or complex traffic conditions. Drivers need sufficient time to regain situation awareness in order to effectively take back control, a challenge that may become more critical the longer the driver has been “out of the loop”. So far, this means that drivers must continue to monitor the vehicle drive itself at all times and the systems can only be used safely in restricted traffic situations that represent relatively low crash risk in the first place.

It is everyone’s expectation, however, that by adding V2X communication, improved 360 degree sensing capabilities, occupant status monitoring and smarter algorithms, a safe system can be achieved in the foreseeable future, which will minimize and ultimately eliminate (crashes due to) driver error. Hands-free driving will open the door to completely new concepts that are offering a high degree of flexibility in design, layout and seating arrangements. From an occupant crash protection perspective, this means that restraint systems will likely become more seat-centric and that the classic approach where belt and bags systems are validated against a limited number of load cases and occupant seating positions will need to be revisited. The continuous situation-awareness of the vehicle itself, facilitated by surround sensors and communication, and that of the occupants inside, will allow for more integrated safety functions across sensors and actuators. This, in turn, can improve pre-crash interventions and enhance the efficiency of passive safety systems.

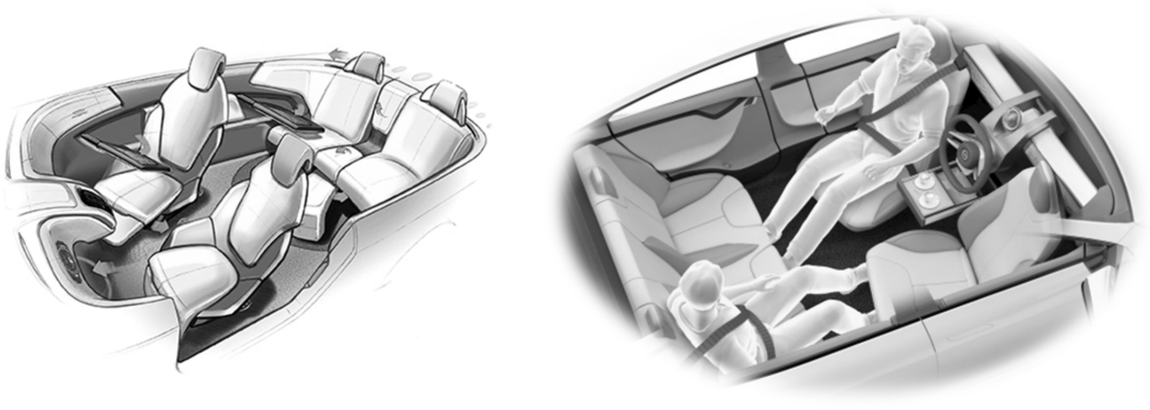

Fig. 3. Future seating concepts for automated driving. Source: Johnsons Controls (Left) / Rinspeed (Right).

With over 1.2 billion vehicles on the world's roads and the average age of vehicles on the road rising to over 10 years, it is a given that automated and self-driving vehicles will have to operate in a mixed traffic environment with manually driven cars for many years to come. The accident distribution of automated cars will be notably different from today’s cars, as they are expected to cause less crashes, automated cars still will be involved in accidents with other, manually driven vehicles and road users. Improving the level of safety of all vehicles on the road, regardless of level of automation, therefore deserves our continued attention. This remains particularly true for the vehicles sold in the most countries, that do not meet minimum safety standards and that do not seem to benefit from the advancements made in high income markets over the last decades.

## V. DISCUSSION

Over the years, the consumer information programs have greatly benefited from the biomechanical research into biofidelic anthropometric test devices, injury criteria, test methods, etc. reported at this conference and elsewhere. In return, NPAC has, through an update of the safety law, offered a mechanism by which improved insight or tools can be introduced into the design of new vehicles much faster than would otherwise be possible. Gradually, the vehicle industry has come to terms with consumer ratings and has learned to use the system to its advantage, especially when it comes to the emerging crash avoidance technologies.

But whereas NCAP's strength is in its ability to follow closely the technology development by industry and take account of local market circumstances, it is also true that this has led to a wide variety of test conditions and inherently different rating schemes applied around the world. The criticism about the lack of harmonization is certainly justified in some instances, in particular when different test speeds, barriers and crash dummies are used to evaluate a car's performance in what is essentially the same real world crash scenario. On the other hand, there are many good reasons too to be different, not in the least because the cars built around the world are so diverse. Recently, more efforts have gone into cooperation between test programs at the development phase, for instance on the definition of a common 3D "soft" vehicle target for AEB testing.

### *Priorities for research*

Field data should continue to dictate the direction of future activity in biomechanics and assessment methods. Vulnerable road users, such as cyclists and motorcyclists but also children, remain an important priority. As automation in cars becomes more mainstream, new crash scenarios and priorities may emerge and surveillance systems should be in place to ensure high quality data will be collected on the circumstances of a crash and the role of man and machine.

There is a high expectation that vehicle automation will lead to innovations in the in-vehicle environment. This will lead to a potentially more complex loading environment for future restraint systems. The newest generation of crash test dummies, humanlike as they may be, are still limited to generalised sizes, body type and posture and will, as a result, not be able to provide all the answers needed. Human body models can complement future assessment strategies to provide a more rigorous and complete evaluation of structure and restraint performance. However, the application of virtual testing as part of a safety rating is not without its challenges. It would require higher levels of standardisation and version control of human body models, easy-to-use injury criteria that can be applied to human models and a procedure that allows the objective verification of performance of vehicle models without compromising the intellectual property of the vehicle manufacturer. Euro NCAP's assessment of deployable systems for pedestrian protection [51], which uses physical as well as virtual testing, sets an example of how this could be achieved.

As long as there are clear categories of crash avoidance systems that address typical accident scenarios and where the contribution of the driver is limited, the "spot testing" approach currently followed by NCAPs will remain beneficial. Verifying the performance on a system level in idealized conditions has the advantage of being able to set clear engineering targets, raise consumer awareness and effectively drive best practice and higher equipment fitment in the market. The availability of 3-dimensional test targets for pedestrians, cars, cycles and motorcycles will allow the recreation of more complex, critical traffic scenarios on the track in the coming years. However, as safety functions become further integrated and vehicles begin to rely on connectivity with infrastructure and other road users – in other words become truly cooperative – it is unlikely that track testing alone will be sufficiently meaningful or conclusive to steer improvements in industry or to inform the consumer. Further research is needed on many aspects related to verifying semi- and fully autonomous vehicle functions and on the human factors involved.

## VI. CONCLUSIONS

Most consumers will have no personal experience on which to judge the crash safety of their car. Are they happy with the level of safety offered? Can they specify what level they want? Can they assess whether this objective has been met? Clearly, without objective and transparent safety information, these questions would be impossible to answer. This underlines the importance of public safety ratings and justifies why NCAPs around the world continue to develop their comparative safety tests. Moreover, it explains why consumer ratings continue to have an impact, not only with consumers but also more and more with public and private fleet managers to help them ensure that their vehicle fleet provides acceptable levels of protection to their employees.

A consumer rating system that is rooted firmly on real life experiences but which closely follows the technological innovations in the marketplace can deliver the most benefit for society. For this reason, links to road safety and biomechanical research as well as to the automotive industry are essential. The NCAPs together have achieved much to be proud of, but there is still important work to be done: in low and middle income markets to ensure that zero star cars will be a thing of the past, and in developed markets to bring down road fatalities and injuries even further.

The NCAP community plans to engage in the roll out of vehicle automation as a way to dramatically improve vehicle safety and safe driving. It will continue to promote best safety practice when vehicles start to have elements fitted which support automated driving and to ensure that the vehicle manufacturer remains responsible for safe operation of the system. Consumer acceptance of these systems and objective, independent reassurance of their performance will play a key part in the transition that is ahead of us.

## VII. ACKNOWLEDGEMENT

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## IX. APPENDIX

TABLE I-A

VEHICLE SAFETY RATINGS (2016) – AMERICAS, EUROPE AND AUSTRALASIA

| Organization | Testing method | Evaluation method |
|---|---|---|
| **US NCAP**<br>(USA)<br>*www.safercar.gov* | • Full width frontal (rigid barrier; 35mph).<br>• Barrier side (moving barrier; 38.5mph).<br>• Pole oblique (20mph).<br>*• Fishhook Maneuver & Static Stability Factor (Roll over).*<br>*• FCW, LDW and Rearview camera confirmation tests (not included in Vehicle Safety Score).* | Vehicle Safety Score with 5 levels based on overall front; overall side; overall roll-over scores.<br>*+ Recommended advanced technologies.* |
| **IIHS**<br>(USA)<br>*www.iihs.org* | • ODB frontal (deformable barrier; 64km/h).<br>• SOB frontal (rigid barrier; 64km/h).<br>• Barrier side (moving SUV barrier; 50km/h).<br>• Seat/head restraint evaluation (IIWPG).<br>• Roof strength test.<br>*• Front Crash Prevention (AEB low speed).*<br>*• Headlight Test (not in overall assessment).*<br>• LATCH (not in overall assessment). | Overall evaluation based on body deformation and occupants injuries with 4 levels. Qualifiers for "Top Safety Pick" and "Top Safety Pick+". |
| **Latin NCAP**<br>(Middle and South America)<br>*www.latincap.com* | • ODB frontal (deformable barrier; 64km/h).<br>• Barrier side (moving EEVC barrier; 50km/h).<br>• Child protection (ODB/MDB; CRS installation and provisions).<br>• Pre-requisites for higher star levels: Standard ABS, ESC, SBR, Pole side impact. | Separate adult and child star ratings based on body deformation and occupants injuries with 5 levels. |
| **Euro NCAP**<br>(Europe)<br>*www.euroncap.com* | • ODB frontal (deformable barrier; 64km/h).<br>• Full width frontal (rigid barrier; 50 km/h).<br>• Barrier side (moving AE barrier; 50km/h).<br>• Pole oblique (29km/h).<br>• Seat/head restraint evaluation (IIWPG, SRA-low, SRA-high).<br>• Child protection (ODB/MDB; CRS installation and provisions).<br>• Pedestrian subsystem (40 km/h, head; upper and lower leg).<br>*• Pedestrian detection (AEB Pedestrian).*<br>• Seatbelt reminder (all seats).<br>*• Speed assistance system (SFIL, MSA and ISA).*<br>*• LDW and LKA confirmation test.*<br>*• Front Crash Prevention (AEB low speed, high speed).*<br>• Advanced Rewards (Beyond NCAP). | Overall Safety Rating based on Adult Occupant Protection; Child Occupant Protection; Pedestrian Protection; Safety Assist with 5 levels.<br>*+ Advanced Rewards* |
| **Australasian NCAP**<br>(Australia and NZ)<br>*www.ancap.com.au* | • ODB frontal (deformable barrier; 64km/h).<br>• Barrier side (moving EEVC barrier; 50km/h).<br>• Pole side (29km/h).<br>• Seat/head restraint evaluation (IIWPG).<br>• Pedestrian subsystem (head; upper and lower leg).<br>• Seatbelt reminder (all seats).<br>*• Mandatory and optional safety assist technologies (SAT).* | Overall Safety Rating based on combined score for crash and SBR; SAT; Pedestrian; Whiplash Protection with 5 levels.<br>*Note: Aligning with Euro NCAP from 2018* |

TABLE I-B

VEHICLE SAFETY RATINGS (2016)- FAR EAST, SOUTHEAST ASIA AND INDIA

| Organization | Testing method | Evaluation method |
|---|---|---|
| **JNCAP**<br>(Japan)<br>*www.nasva.go.jp* | ・Full width frontal (rigid barrier; 55 km/h).<br>・ODB frontal (deformable barrier; 64km/h).<br>・Barrier side (moving EEVC barrier; 55km/h).<br>・Seat/head restraint evaluation (JARI).<br>・Pedestrian subsystem (35 km/h, head; lower leg).<br>・Seatbelt reminder (all seats).<br>*・Braking performance test (not included in vehicle rating).*<br>*・FCW, LDW and All-round-view monitor confirmation tests (not included in vehicle rating).* | Overall Safety Rating based Occupant Protection, Pedestrian Protection and Seatbelt Reminder with 5 levels.<br>*+ ASV and ASV+ awards* |
| **KNCAP**<br>(Republic of Korea)<br>*www.car.go.kr* | ・Full width frontal (rigid barrier; 56 km/h).<br>・ODB frontal (deformable barrier; 64km/h).<br>・Barrier side (moving AE barrier; 55km/h).<br>・Pole side (29km/h).<br>・Seat/head restraint evaluation (IIWPG).<br>・Pedestrian subsystem (40 km/h, head; upper and lower leg).<br>・Seatbelt reminder (all seats).<br>*・Fishhook Maneuver & Static Stability Factor (Roll over).*<br>*・Braking performance test.*<br>*・LDW confirmation test.*<br>*・Front Crash Prevention (AEB high speed).* | Overall Safety Grade based on Crash Safety, Pedestrian Safety, Driving Safety with 5 levels.<br>*+ additional points for SBR, LDW and FCW* |
| **China NCAP**<br>(People's Republic of China)<br>*www.c-ncap.org* | ・Full width frontal (rigid barrier; 50 km/h).<br>・ODB frontal (deformable barrier; 64km/h).<br>・Barrier side (moving EEVC barrier; 50km/h).<br>・Seat/head restraint evaluation (IIWPG).<br>・Additional points: Standard ESC, SBR and side curtain airbag. | Overall Safety Rating with 5 levels. |
| **ASEAN NCAP**<br>(South East Asia)<br>*www.aseancap.org* | ・ODB frontal (deformable barrier; 64km/h)<br>・Child protection (ODB; CRS based and interfaces)<br>・Pre-requisites for higher star levels: Standard ESC, driver SBR and UN R95 compliance | Separate adult and child star ratings based on body deformation and occupants injuries with 5 levels. |
| **Global NCAP**<br>(India)<br>*www.globalncap.org* | ・ODB frontal (deformable barrier; 64km/h).<br>・Child protection (ODB; CRS based and interfaces). | Separate adult and child star ratings based on body deformation and occupants injuries with 5 levels. |