[Note from NHTSA: The Administrator signed the following document on December 8, 2015, and we are submitting it for publication in the Federal Register. While we have taken steps to ensure the accuracy of this Internet version of the document, it is not the official version. Please refer to the official version in a forthcoming Federal Register publication. You can access the Federal Register at: www.federalregister.gov]

DEPARTMENT OF TRANSPORTATION

National Highway Traffic Safety Administration

[Docket No. NHTSA-2015-0119]

New Car Assessment Program (NCAP)

AGENCY: National Highway Traffic Safety Administration (NHTSA), Department of Transportation (DOT).

ACTION: Request for comments.

SUMMARY: NHTSA's New Car Assessment Program (NCAP) provides comparative information on the safety of new vehicles to assist consumers with vehicle purchasing decisions and encourage motor vehicle manufacturers to make vehicle safety improvements. To keep pace with advancements in occupant protection and the introduction of advanced technologies, NHTSA has periodically updated the program. This notice describes and seeks comments on NHTSA's plan to advance the capabilities and safety outcomes of NCAP.

DATES: Comments should be submitted no later than [60 days from publication date].

ADDRESSES: Comments should refer to the docket number above and be submitted by one of the following methods:

- *Federal Rulemaking Portal*: www.regulations.gov. Follow the online instructions for submitting comments.
- *Mail*: Docket Management Facility, U.S. Department of Transportation, 1200 New Jersey Avenue SE., West Building Ground Floor, Room W12-140, Washington, DC 20590-0001.
- *Hand Delivery*: 1200 New Jersey Avenue SE., West Building Ground Floor, Room W12-140, Washington, DC, between 9 a.m. and 5 p.m. EST, Monday through Friday, except Federal holidays.
- *Instructions*: For detailed instructions on submitting comments see the Public Participation heading of the **SUPPLEMENTARY INFORMATION** section of this document. Note that all comments received will be posted without change to www.regulations.gov, including any personal information provided.
- *Privacy Act*: Anyone is able to search the electronic form of all comments received into any of our dockets by the name of the individual submitting the comment (or signing the comment, if submitted on behalf of an association, business, labor union, etc.). You may review DOT's complete Privacy Act Statement in the **Federal Register** published on April 11, 2000 (65 FR 19477). For access to the docket to read background documents or comments received, go to www.regulations.gov or the street address listed above. Follow the online instructions for accessing the dockets.

FOR FURTHER INFORMATION CONTACT: For crashworthiness issues, you may contact Jennifer N. Dang, Division Chief, New Car Assessment Program, Office of Crashworthiness Standards (Telephone: 202-366-1810). For crash avoidance and advanced technology issues, you may contact Clarke B. Harper, Crash Avoidance NCAP Manager, Office of Crash Avoidance Standards (Telephone: 202-366-1810). For legal issues, you may contact Stephen P. Wood, Office of Chief Counsel (Telephone: 202-366-2992). You may send mail to any of these officials at the National Highway Traffic Safety Administration, 1200 New Jersey Avenue SE., West Building, Washington, DC 20590-0001.

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I. Executive Summary

This notice announces the National Highway Traffic Safety Administration's (NHTSA) plans to update the New Car Assessment Program (NCAP). When NCAP first began providing consumers with vehicle safety information derived from frontal crashworthiness testing in 1978, consumer interest in vehicle safety and manufacturers' attention to enhanced vehicle safety features were relatively new, and there were 50,133 motor vehicle related deaths. Today, consumers are more educated about vehicle safety as it has become one of the key factors in their vehicle purchasing decisions. Vehicle manufacturers have responded by offering safer vehicles and incorporating enhanced safety features. All of this has translated into improved vehicle safety performance and higher NCAP star ratings. These successes have contributed to the recent historic reductions in motor vehicle fatalities (32,719 in 2013).

While NHTSA's NCAP has raised consumer awareness of vehicle safety and incentivized the production of safer vehicles, thousands of lives continue to be lost every year in motor vehicle crashes.

This notice announces the beginning of a process NHTSA believes will provide the agency with significantly enhanced tools and techniques for better evaluating the safety of vehicles, generating star ratings, and stimulating the development of even safer vehicles for American consumers, which the agency believes will result in even lower numbers of deaths and injuries resulting from motor vehicle crashes. These include:

- A new frontal oblique test to address a crash type that continues to result in deaths and serious injuries despite the use of seat belts, air bags, and the crashworthy structures of late-model vehicles;
- Use of the THOR 50th percentile male (THOR-50M) anthropomorphic test device (ATD – i.e. crash test dummy) in the frontal oblique and full frontal tests because of its advanced instrumentation and more human-like (biofidelic) response to the forces experienced in these crashes;
- Use of the WorldSID 50th percentile male ATD (WorldSID-50M) in both side pole and side moveable deformable barrier (MDB) tests because of its advanced instrumentation and enhanced biofidelic (human-like) properties;
- Pedestrian crashworthiness testing to measure the extent to which vehicles are designed to minimize injuries and fatalities to pedestrians struck by vehicles;
- An update of the rollover static stability factor (SSF) risk curve using only crash data from newer electronic stability control (ESC) equipped vehicles;
- The addition of a crash avoidance rating based on whether a vehicle offers any of the multiple technologies that will be added to NCAP and whether the technologies meet NHTSA performance measures;

- These technologies would include forward collision warning, lane departure warning, blind spot detection, lower beam headlighting technologies, semi-automatic headlamp beam switching, amber rear turn signal lamps, rear automatic braking and pedestrian automatic emergency braking. (A decision concerning the addition of crash imminent braking and dynamic brake support to the technologies recommended by NCAP is the subject of a separate proceeding recently published.[1])

- 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.

This notice describes the agency's plans for implementing the new tools and approaches referenced above. NHTSA intends to implement these enhancements in NCAP in 2018 beginning with the 2019 model year (MY). The agency encourages all interested parties to provide the agency with comprehensive comments.

As part of its efforts to support this NCAP upgrade, the agency will be completing additional technical work. The results of these efforts will be placed in the Docket as they are completed. Accordingly, we recommend that interested people periodically check the Docket for new material.

II. Background

In 2013, 32,719 people died on U.S. roads. In addition, 2,313,000 more were injured. The National Highway Traffic Safety Administration's (NHTSA) mission is to save lives, prevent injuries and reduce vehicle-related crashes.

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[1] See www.regulations.gov, Docket No. NHTSA-2015-0006-0024.

The agency uses several approaches to carry out its mission including regulations, defect investigations and recalls, and education programs. The New Car Assessment Program (NCAP) is a consumer education approach that the agency uses to help accomplish its safety mission. NCAP provides comparative information on the safety performance and features of new vehicles to: (1) assist consumers with their vehicle purchasing decisions, (2) encourage manufacturers to improve the current safety performance and features of new vehicles, and (3) stimulate the addition of new vehicle safety features. NCAP has a proven legacy of driving vehicle safety improvements effectively and quickly. Advancements to NCAP represent an opportunity to save more lives and prevent more injuries.

NHTSA established NCAP in 1978 in response to Title II of the Motor Vehicle Information and Cost Savings Act of 1972.[2] Beginning with MY 1979, NHTSA began testing passenger vehicles for frontal impact safety based on injury readings gathered from anthropomorphic test devices (ATDs, also known as crash test dummies) during crash tests. Star ratings were introduced in MY 1994 as a more consumer-friendly approach to conveying the relative safety of vehicles subject to NCAP's crash tests.[3] The agency added crash tests and ratings for side impact safety beginning in MY 1997.[4] A new test for rollover resistance assessment was added to the rating system in MY 2001 based on a vehicle's measured static properties as reflected by a calculation known as the Static Stability Factor (SSF).[5] Beginning

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[2] Motor Vehicle Information and Cost Savings Act, Pub.L. 92–513, 86 Stat. 947 (1972).
[3] See 69 FR 61072. Docket No. NHTSA-2004-1876. Available at https://federalregister.gov/a/04-23078.
[4] U.S. Department of Transportation, Office of Public Affairs. (1997). NHTSA Releases Side Crash Test Results in New Consumer Information Program [Press Release]. Retrieved from www.nhtsa.gov/About+NHTSA/Press+Releases/1997/NHTSA+Releases+Side+Crash+Test+Results+in+New+Consumer+Information+Program.
[5] U.S. Department of Transportation, Office of Public Affairs. (2001). U.S. Department of Transportation Announces First Rollover Resistance Ratings [Press Release]. Retrieved from

with MY 2004, the NCAP rollover resistance rating was amended so that the rating is based on not only the SSF but also the results of a dynamic vehicle test.[6]

On January 25, 2007, NHTSA published a Federal Register notice announcing a public hearing and requesting comments on an agency report titled, "The New Car Assessment Program (NCAP) Suggested Approaches for Future Enhancements."[7] Following the receipt of written comments and testimony at a March 7, 2007, public hearing, NHTSA published a notice on July 11, 2008, announcing specific changes to NCAP.[8] The agency made frontal and side crash ratings criteria more stringent by upgrading crash test dummies including new 5th percentile female dummies, establishing new injury criteria, adding a new side pole crash test, and creating a single overall vehicle score that reflects a vehicle's combined frontal crash, side crash, and rollover ratings. In addition, the agency added information about the presence of advanced crash avoidance technologies in vehicles as part of NCAP. Technologies that were demonstrated to have a potential safety benefit and meet NHTSA's performance test measures were recommended to consumers on *www.safercar.gov*, where NCAP ratings and other vehicle safety information were posted. The agency implemented these NCAP enhancements beginning with MY 2011 vehicles. Subsequent to these changes to the program, the agency then initiated a rulemaking to modify the NCAP-related information required on the Monroney label.

When NCAP was first launched in 1978, vehicle manufacturers were slow to respond to the program by way of redesigning or making changes to their vehicles to improve vehicle safety

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www.nhtsa.gov/About+NHTSA/Press+Releases/2001/U.S.+Department+of+Transportation+Announces+First+Rollover+Resistance+Ratings.

[6] U.S. Department of Transportation, Office of Public Affairs. (2003). NHTSA Announces New Rollover Test [Press Release]. Retrieved from www.nhtsa.gov/About+NHTSA/Press+Releases/2003/NHTSA+Announces+New+Rollover+Test.

[7] See 72 FR 3473. Docket No. NHTSA-2006-26555-0006. Available at https://federalregister.gov/a/E7-1130.

[8] See 73 FR 40016. Docket No. NHTSA-2006-26555-0114. Available at https://federalregister.gov/a/E8-15620.

performance ratings. Following the implementation of the July 11, 2008, NCAP upgrade, many new vehicles achieved 4- and 5- star NCAP ratings very quickly, even in new test scenarios with newly introduced ATDs.[9]

This signaled a new challenge for NHTSA. While the agency applauds the response of manufacturers who rise to meet the safety challenges set forth by NCAP, NHTSA is concerned that a high percentage of vehicles receiving 4 and 5 stars diminishes the program's ability to identify for consumers vehicles with exceptional safety performance. NHTSA believes enhancements to NCAP should be dynamic to address emerging available technologies, so that it can incentivize vehicle manufacturers to continue to make safety improvements to their vehicles.

Other NCAPs have formed around the world in the time since NHTSA's NCAP was first established. Today the following NCAP programs operate with missions and goals similar to those of the U.S. NCAP: Australasian New Car Assessment Program (ANCAP), New Car Assessment Program for Southeast Asia (ASEAN NCAP), China New Car Assessment Program (C-NCAP), The European New Car Assessment Program (Euro NCAP), Japan New Car Assessment Program (JNCAP), Korean New Car Assessment Program (KNCAP), and Latin American and the Caribbean New Car Assessment Program (Latin NCAP). These other NCAPs are in various stages of development, with Euro NCAP, formed in 1997, among the more well-established programs. Euro NCAP's test protocols are often referenced by other NCAP programs.

In the United States, in addition to NHTSA's NCAP, there is also the Insurance Institute for Highway Safety/Highway Loss Data Institute, an organization funded largely by the

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[9] Park, B., Rockwell, T., Collins, L., Smith, C., Aram, M., "The Enhanced U.S. NCAP: Five Years Later," The 24th International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 15-0314, 2015.

insurance industry that conducts its own vehicle testing and consumer vehicle safety information program.[10]

These programs and NHTSA's NCAP are all associated with Global NCAP,[11] a recently formed international organization with a multi-faceted mission including (1) supporting the development of new consumer crash test programs in emerging markets, (2) providing a platform for associated NCAPs to share information regarding best practices and approaches to promoting vehicle safety, and (3) researching vehicle safety technology innovations and ways of helping to advance those technologies.

III. April 5, 2013, Request for Comments - Brief Overview of Comments Received

On April 5, 2013, NHTSA published a notice (78 FR 20597) requesting comments on a number of areas relating to the agency's NCAP. The agency requested comment in areas in which the agency believes enhancements to NCAP could be made either in the short term or over a longer period time. A total of 58 organizations or individuals submitted comments in response to the April 5, 2013, "Request for comments" (RFC) notice. Comments were received from associations, consultants and research organizations, consumer organizations and advocacy groups, a government agency, an insurance company and an insurance organization, a publisher, suppliers to the automobile industry, a university, and vehicle manufacturers. The remaining comments were submitted by individuals (some anonymously). See *www.regulations.gov*, Docket No. NHTSA-2012-0180 for a full listing of the 58 commenters.

What follows is a brief summary of comments submitted in response to the April 5, 2013, RFC notice and that are relevant to today's notice. Comments received on a number of topics are

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[10] For information concerning the IIHS program see http://www.iihs.org/iihs/ratings.
[11] See www.globalncap.org. This website also includes links to all NCAP programs around the world.

not summarized in this document because this notice does not focus on all topics included in the April 5, 2013, notice.[12]

A. Crashworthiness Areas

1. Test Dummies

Several commenters supported the general notion of improving test dummies used in NCAP. Concerns included the desire to work with the agency in the development of improved crash test dummies, the need for users to have sufficient lead time to obtain and gain experience with new dummies before they need to start using them in the design and development process, and the belief that new dummies and injury criteria should be formally introduced through a standardized regulatory process with sufficient lead time or a phase-in.

a. THOR 50th Percentile Male Metric ATD (THOR-50M)

While there was support for using the Test device for Human Occupant Restraint (THOR) 50M dummy in frontal NCAP, commenters were apprehensive about repeatability, reproducibility, durability, and ease-of-use issues. They questioned whether exclusive use of THOR-50M, instead of the Hybrid III 50th percentile male (HIII-50M) ATD, would result in incremental safety advances. One commenter, however, urged NHTSA to take the lead in harmonizing the performance and design of the THOR-50M, as it has for the WorldSID-50M dummy under the UNECE World Forum for Harmonization of Vehicle Regulations (WP.29).

[12] These include a possible silver car rating for older occupants, new test protocols for electric vehicles, comparative barrier testing for a frontal crash rating, advanced child dummies, the Hybrid III 95th percentile dummy, rear seat belt reminders, a possible family star rating, carry back ratings, adjustments to the baseline injury risk, and some ideas for providing better consumer information.

b. WorldSID 50th Percentile Male ATD (WorldSID-50M)

While generally supporting the introduction of the WorldSID-50M into NCAP for side impact testing, some commenters noted the need for injury criteria for this ATD and the need for those criteria to be harmonized with those being developed by Euro NCAP. Some commenters expressed concern about the cost and lead time required for manufacturers to obtain WorldSID dummies. Remaining technical issues with respect to the WorldSID 5th percentile female dummy (WorldSID-5F) were noted by a few commenters. One commenter suggested that the dummy should be incorporated into NCAP once the issues are resolved and the dummy is incorporated into Title 49 Code of Federal Regulations (CFR) Part 572, "Anthropomorphic test devices."

2. New and Refined Injury Criteria: Brain Injury Criterion, SID-IIs Thoracic and Abdomen Deflection, and Neck Injury Criterion, and Lower Leg

The agency sought public comment and supporting information on ATD injury criteria used to predict injury potential in vehicle crash tests.

a. Brain Injury Criterion (BrIC)

BrIC is an injury criterion for assessing brain injury resulting from head rotation, regardless of whether or not there is a head impact. Some commenters supported the introduction of BrIC into NCAP while others expressed reservations about the current state of knowledge and therefore opposed BrIC until more information becomes available.

b. SID-IIs Thoracic and Abdomen Deflection Criteria

Some commenters supported the inclusion of thoracic and abdominal rib deflection criteria for the SID-IIs dummy in side NCAP. Those who opposed using these injury criteria in

NCAP indicated that changes to the injury criteria should first be considered through a rulemaking process as part of a possible revision to Federal Motor Vehicle Safety Standard (FMVSS) No. 214, "Side impact protection."

c. Neck Injury Criterion (Nij)

All comments on the neck injury criterion (Nij) were critical of the current risk curve and encouraged the agency to make revisions. Commenters generally suggested that the current Nij risk curve overstates the risk of neck injury, which in their opinion undercuts the validity of certain NCAP vehicle safety ratings.

d. Lower Leg

There were only a few comments on lower leg injury criteria, but those addressing this issue generally supported the idea of incorporating lower leg injury criteria into NCAP. Instruments to gather lower leg data must be thoroughly vetted, one commenter said, and another suggested that changes to lower leg injury criteria should be dealt with concurrently in a FMVSS 208 rulemaking and in NCAP.

3. Other Crashworthiness Areas

a. Pedestrian Protection

Many of the commenters in this area supported NHTSA basing whatever it does with respect to pedestrian protection on Global Technical Regulation (GTR) No. 9. Some did not support including pedestrian safety in NCAP, arguing instead that it should be the subject of regulation. Two commenters specifically urged NHTSA to consider using a type of "point system" similar to the one currently used by Euro NCAP to reward the implementation of advanced safety equipment such as pedestrian protection.

b. Rear Seat Occupants in Frontal Crashes

Many commenters spoke favorably about the potential benefits that may be derived from enhancing safety for rear seat occupants. Those in favor of the agency conducting additional tests to assess the rear seat environment expressed support for using the Hybrid III 5th percentile female (HIII-5F) dummy in NCAP, but opinions varied regarding what parameters should be evaluated in the test. Several commenters noted that current technologies used to protect occupants in the front seats may not be well-suited to protect those in the rear seat. One commenter disagreed, however, saying front seat technologies should be considered for possible application to the rear seat. Several other commenters specifically cautioned against changes in the back seat environment that could benefit one type of rear seat occupant while possibly adversely affecting others.

B. Crash Avoidance and Post-Crash Technologies

1. General Crash Avoidance/Post-Crash Technologies

The inclusion of crash avoidance technologies in NCAP was supported by many commenters. Only one commenter specifically indicated that more data on real-world safety benefits would be needed before they could comment on whether adding more technologies to NCAP is appropriate. Particular interest was expressed in the following technologies: blind spot detection, lane departure prevention/lane keeping assist, forward automatic pedestrian detection and braking, advanced lighting, crash imminent braking, dynamic brake support, and advanced automatic crash notification.

Even among those who supported a specific technology as a possible enhancement to NCAP, there were often differences in the details of how and when the particular enhancement should be pursued and implemented. Though there was a general sense among the commenters

that adoption rates of these technologies will continue to rise in the new light-vehicle marketplace and therefore they should be incorporated into NCAP, there were overwhelming differences in viewpoints about the conditions under which these technologies should be incorporated into NCAP.

2. Blind Spot Detection (BSD)

Most of those who commented on BSD systems agreed that this technology has the potential to provide safety benefits although safety benefits estimates were not provided. Only some of these commenters specifically indicated that BSD should be included in NCAP. One commenter suggested that a vehicle should be given "extra points" in NCAP if equipped with BSD while another said that BSD should be included in the NCAP 5-star safety rating system. Another commenter said that it should not be included in a star rating and suggested instead including BSD and lane change assist systems in the current NCAP approach of identifying advanced crash avoidance technology systems with a check mark on *www.safercar.gov* for vehicles equipped with those systems and that meet NCAP's performance test criteria.

3. Advanced Lighting[13]

Most commenters spoke favorably of the potential for advanced lighting technologies to have a positive impact on vehicle safety. The favorable comments suggested these commenters support the inclusion of advanced lighting in NCAP; however, only a few of the commenters clearly stated that advanced lighting should be included in NCAP.

[13] Advanced lighting in the context of this program currently includes lower beam headlighting performance, semi-automatic headlamp beam switching, and amber rear turn signal lamps.

Other commenters expressed the need for additional research into the benefits of advanced lighting. Commenters also discussed the need to modify FMVSS No. 108, "Lamps, reflective devices, and associated equipment," so that advanced lighting technologies now approved for use in other areas of the world can be introduced in the United States.

4. Crash Imminent Braking (CIB) and Dynamic Brake Support (DBS)

Most of those commenting on the 2013 RFC notice supported including CIB and DBS in NCAP in some way. On January 28, 2015, NHTSA published an RFC notice in the Federal Register announcing the agency's plan to recommend these technologies in NCAP.[14] Comments received from the 2013 RFC notice were conveyed as part of that proceeding and will not be repeated here. The final agency decision notice on the inclusion of these technologies in NCAP was recently published in the same docket.

C. Potential Changes to the Rating System

1. Update of the Rollover Risk Curve

Five of those who commented in this area focused on the importance of revising the distribution of crash types used in calculating the Overall Vehicle Score to reflect the reduction in rollover crashes among ESC-equipped vehicles.

Those who offered specific suggestions regarding the appropriate weighting factor for rollover in determining a vehicle's Overall Vehicle Score suggested that it should be 10 percent. In addition to the 10 percent for rollover, one commenter mentioned a study it had commissioned that indicated the weighting factor for frontal and side crash ratings should be 54 percent and 36

[14] See 80 FR 4630. Docket No. NHTSA-2015-0006. Available at https://federalregister.gov/a/2015-01461.

percent, respectively, as opposed to the current weighting factors of 42 percent for frontal, 33 percent for side, and 25 percent for rollover.

2. Advanced Technology Systems

Some commenters asked the agency to maintain its current approach of recommending the technologies instead of rating them while others supported rating the technologies with stars. A few commenters preferred a combined crash avoidance and crashworthiness rating while others suggested that they should remain as separate ratings. Euro NCAP's "point system" approach was also mentioned as a possibility for rating, ranking, or assessing various crash avoidance technologies.

IV. Overview of This Notice

A. Purpose and Rationale

The purpose of this notice is to solicit public comment on the agency's plan to advance the capabilities and safety outcomes of NHTSA's NCAP program. The agency aims to have NCAP continue to serve as a world leader in providing consumers with vehicle safety information generated by the latest available vehicle safety assessment techniques and tools. The agency believes that NCAP works best if the program keeps pace with advancements in safety technologies and capabilities so that consumers can be assured that evaluation criteria used provide the most thorough measure of vehicle safety possible using the current state-of-the-art so that only truly exceptional vehicles achieve 4- and 5-star ratings.

As discussed previously, given the high percentage of recent model year vehicles rated by NCAP now receiving 4- and 5-star ratings, it is an opportune time for the agency to consider further refinements to NCAP to assure that only vehicles with truly exceptional safety features and performance will receive 4- and 5-star ratings. In the end, the agency's goal is for the

program to provide a continuing incentive for vehicle manufacturers to further improve the safety of the vehicles they manufacture.

As vehicle safety innovations offering substantial safety potential continue to emerge, the agency believes that it must also use NCAP, its most effective means of encouraging vehicle safety improvements and innovations through market forces, to incentivize vehicle manufacturers to equip their vehicles with these technologies. In addition, the agency must continually strive to expand and improve the safety information that is conveyed to consumers and continually increase the effectiveness with which that information is communicated. To that end, this notice outlines NHTSA's intention to implement a new 5-star rating system to convey vehicle safety information in three major areas – crashworthiness, crash avoidance, and pedestrian protection.

The agency considered a variety of information in developing the potential new approaches for NCAP discussed in this RFC notice. The agency has reviewed comments submitted in response to the April 5, 2013, notice, evaluated its current research activities, and considered recent recommendations from the National Transportation Safety Board (NTSB) and other consumer organizations and advocacy groups that encourage the inclusion of advanced technologies as part of the NCAP 5-star safety rating system.[15]

This RFC notice outlines the agency's plan for this NCAP upgrade. It describes in detail new program areas that NHTSA intends to add to NCAP, the timeline to implement these enhancements, and a new way of calculating star ratings. The agency recognizes that by sharing, and seeking comment on its intentions, it allows the public an opportunity to inform the agency

[15] On June 8, 2015, the agency received a "Safety Recommendation" letter from the NTSB urging NHTSA to expand the NCAP 5-star safety rating system to include a scale that rates the performance of advanced technologies, specifically forward collision avoidance systems.

of information relevant to this NCAP upgrade. In addition, this RFC notice provides the automotive industry the opportunity to begin taking the steps that will be needed to adapt to the enhancements in this NCAP upgrade.

In the April 5, 2013, RFC notice, NHTSA noted "there are four prerequisites for considering an area for adoption as a new NCAP enhancement."[16] First, a safety need must be known or be capable of being estimated based on what is known. Second, vehicle and equipment designs must exist or at least be anticipated in prototype designs that are capable of mitigating the safety need. Third, a safety benefit must be estimated, based on the anticipated performance of the existing or prototype design. Finally, it must be feasible to develop a performance-based objective test procedure to measure the ability of the vehicle technology to mitigate the safety issue.

To the extent possible, these criteria will be discussed in this RFC notice for each feature being considered. Data may not be available for each element, but NHTSA will consider information to the extent that it is available. NHTSA welcomes any data to support the analysis of these criteria. NHTSA may consider other factors that are not among the criteria listed above. Additionally, NHTSA may weight some of these criteria differently for some features than for others, if NHTSA believes it is in the interest of developing a robust program that encourages safety advancements in the marketplace.

V. Areas under Consideration for Inclusion in or Advancement of NCAP

A. Frontal Crashworthiness

1. Real-World Frontal Crash Data

[16] See 78 FR 20597. Docket No. NHTSA-2012-0180. Available at https://federalregister.gov/a/2013-07766.

In September 2009, NHTSA published a report that sought to describe why people were still dying in frontal crashes despite the use of seat belts, air bags, and the crashworthy structures of late-model vehicles.[17] The study found that many fatalities and injuries could be attributed to crashes involving poor structural engagement between a vehicle and its collision partner. These crashes consisted mainly of corner impacts, oblique crashes, impacts with narrow objects, and heavy vehicle underrides.

To better understand and classify the injuries and fatalities from crashes involving oblique and corner impacts, the agency took a new approach to field data research. A 2011 report detailed this new method to more comprehensively identify frontal crashes based on an alternate interpretation of vehicle damage characteristics.[18] NHTSA incorporated this approach into its efforts to examine frontal crashes occurring in the field data. Furthermore, recognizing that occupant kinematics and restraint engagement differed among frontal crash types, the agency's new method allowed for better identification of frontal crashes with more emphasis on occupant responses than vehicle damage characteristics. When using this method, the population of frontal crashes generated tends to include some crashes that would previously have been classified as side impact crashes. In this, there may be damage located on the side plane of a given vehicle, though the kinematics of the occupants resembles those typically seen in a conventionally coded frontal impact.

In support of this RFC notice, National Automotive Sampling System – Crashworthiness Data System (NASS-CDS) data from case years 2000 through 2013 were chosen for analysis

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[17] Bean, J., Kahane, C., Mynatt, M., Rudd, R., Rush, C., Wiacek, C., National Highway Traffic Safety Administration, "Fatalities in Frontal Crashes Despite Seat Belts and Air Bags," DOT HS 811 202, September 2009.
[18] National Highway Traffic Safety Administration, "NASS Analysis in Support of NHTSA's Frontal Small Overlap Program," DOT HS 811 522, August 2011.

using the new approach. The resulting NASS-CDS data generated for this effort are contained in Appendix I. Crashes were selected to include passenger vehicles involved in a tow-away non-rollover crash with a Principal Direction of Force (PDOF) between 330 degrees and 30 degrees (11 o'clock to 1 o'clock). Only non-ejected, belt-restrained occupants, who sustained AIS 2 and higher severity injuries or were killed, were selected from those crashes. The two crash configurations responsible for the most injuries and fatalities in the resulting frontal crash data set are shown in Table 1 below. They are the co-linear full overlap and the left (driver side) oblique crash modes.

Table 1 shows the number of restrained Maximum Abbreviated Injury Scale (MAIS) 2+ and 3+ injured and fatal occupants seated in the front rows of vehicles involved in left oblique and co-linear full frontal crashes.[19] These are unadjusted, annualized occupant counts. This means that the total weighted counts over the 14-year period are simply divided by 14 to produce an average annual count. Case weights were not adjusted to account for factors such as vehicle age or matching fatality counts in the Fatality Analysis Reporting System (FARS). There were more MAIS 2+ and 3+ injured occupants from left oblique crashes than co-linear full overlap crashes in this dataset. The numbers of fatalities are very similar when comparing both crash types.

Table 1. Distribution of annual restrained MAIS 2+, MAIS 3+, and fatal occupants in left oblique and co-linear frontal crashes

Crash Mode	**Front Row**		
	MAIS 2+	*MAIS 3+*	*Fatal*
Co-linear full overlap	17,634	4,037	640
Left oblique	19,131	5,354	633
Total	**36,765**	**9,392**	**1,273**

Source: NASS-CDS (2000-2013)

[19] The Maximum Abbreviated Injury Scale (or MAIS) is the maximum injury per occupant.

The occupant counts defined in Table 1 were further examined to better understand which individual body regions in both of these frontal crash modes sustained AIS 3+ injuries. The following body regions were used in the classification of injuries: Head (including face injuries, brain injuries, and skull fracture); Neck (including the brain stem and cervical spine); Chest (thorax); Abdomen; Knee-Thigh-Hip; Below Knee (lower leg, feet, and ankles); Spine (excluding the cervical spine); and Upper Extremity.

Figure 1 shows the break-down of drivers with MAIS 3+ injuries in each body region for both frontal crash modes. These unadjusted, annualized counts indicate the number of times a given body region sustained an AIS 3 or higher injury among the drivers in Table 1. Some drivers may be represented in multiple columns. Some key inferences can be made. First, drivers in oblique crashes experienced more MAIS 3+ injuries to nearly every body region than drivers in co-linear crashes. Drivers in oblique crashes experienced more injuries to the head, neck and cervical spine, abdomen, upper extremities, knee/thigh/hip (KTH), and areas below the knee. Though drivers in co-linear crashes experienced more MAIS 3+ chest injuries than drivers in oblique crashes, these injuries were the highest in number for both crash types. Driver injuries in both frontal crash types occurred to a wide variety of body regions.

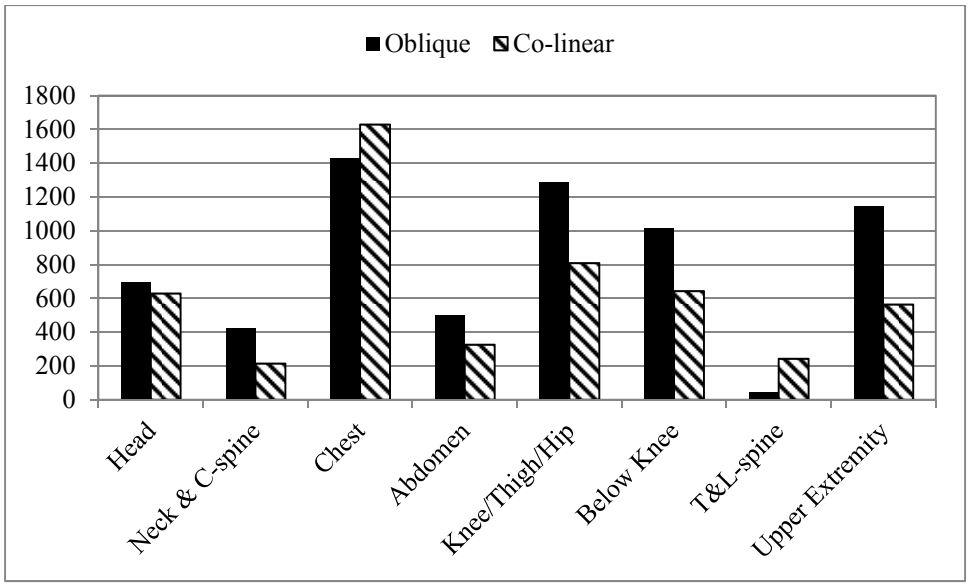

Figure 1. Number of Annual Driver MAIS 3+ Injuries by Body Region in Co-linear and Left Oblique Crashes
Source: NASS-CDS (2000-2013)

Figure 2 is similar to Figure 1, but provides an overview of the MAIS 3+ injuries for the right front passenger instead. It shows a pattern similar to the driver; MAIS 3+ injuries in left oblique crashes outweigh the numbers of similar injuries in co-linear crashes. Right front passengers in left oblique crashes experienced more injuries to the head, neck and cervical spine, chest, abdomen, upper extremities, and KTH regions than right front passengers involved in co-linear full frontal crashes. Injuries for the right front passenger occurred to a wide variety of body regions, which is similar to what was observed for the driver.

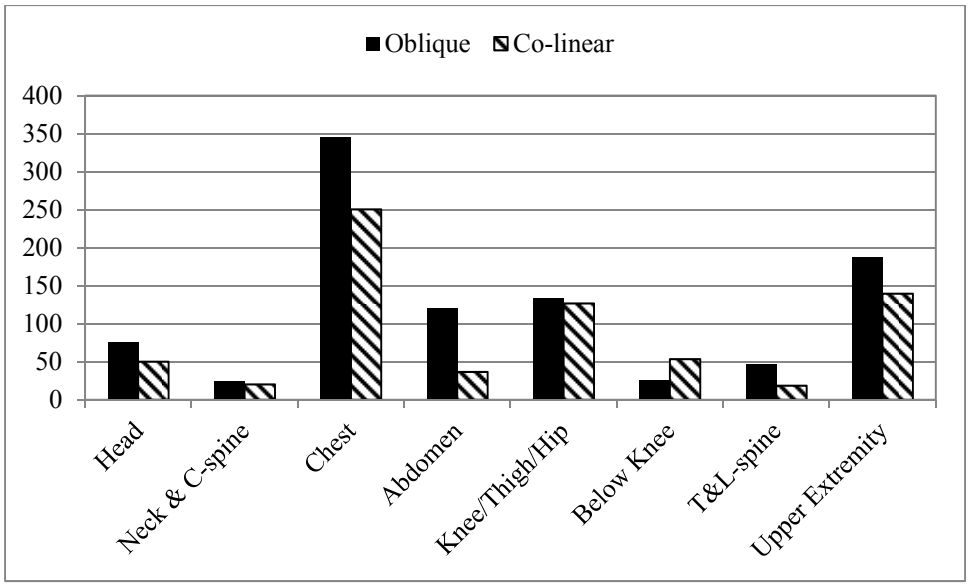

Figure 2. Number of Annual Front Passenger MAIS 3+ Injuries by Body Region in Co-linear and Left Oblique Crashes
Source: NASS-CDS (2000-2013)

This real-world data analysis suggests that there is an opportunity for the agency to continue examining the oblique crash type that was identified as a frontal crash problem by NHTSA in 2009. Real-world co-linear crashes that are represented in FMVSS No. 208, "Occupant crash protection," and the current full frontal NCAP test are also still resulting in serious injuries and fatalities.

2. Full Frontal Rigid Barrier Test

NCAP intends to continue conducting its current full width rigid frontal barrier test at 56 km/h (35 mph). As shown in the 2000-2013 NASS-CDS data discussed earlier, these frontal crashes are still a major source of injuries and fatalities in the field. However, NHTSA intends to update the ATDs to evaluate occupant protection in NCAP's full frontal crash. Rather than using the HIII-50M ATD, NHTSA intends to use the THOR-50M ATD in the driver's seat of full frontal rigid barrier tests conducted for this NCAP upgrade. NHTSA intends to continue using the HIII-5F dummy in the right front passenger's seat of these tests for frontal NCAP, though the

ATD would now be seated at the mid-track position rather than the full-forward position it is currently placed in (based on the current NCAP and FMVSS No. 208 test procedures). In every full width rigid barrier frontal NCAP test, the agency intends to seat another HIII-5F ATD in the second row of the vehicle, behind the right front passenger. The agency is seeking comment on the seating procedures for these dummies in the full frontal rigid barrier test.

The THOR-50M ATD requires a different seating procedure than the currently used HIII-50M ATD. Some modifications are necessary in the areas of adjusting the seat back angle, seat track, and positioning of the legs, feet, shoulder, and other body regions related to the inherent physical characteristics of the THOR-50M ATD. The agency is seeking comment on draft procedures for seating a THOR-50M ATD in the driver's seat of vehicles.[20]

NHTSA seeks comment on an alternative seating procedure for the right front passenger ATD, the HIII-5F. Currently, the HIII-5F ATD is seated in the forward-most seating position for FMVSS No. 208 and NCAP full frontal tests. In light of real-world data gathered from NASS-CDS, (2000-2013 full frontal crashes, with MAIS 2+ injured occupants, discussed further below) the agency intends to conduct research tests with the HIII-5F ATD seated in the right front passenger seat's mid-track location instead of the forward-most location. This data, shown below in Figure 3, indicates that the majority of MAIS 2+ injured occupants sit in a mid- to rear seat track position.[21] The number of right front passengers injured when seated in the full-forward position was the smallest number of occupants seen in this data set. In addition, the right front passenger seats in this data set were most likely to be placed in the forward-mid or middle position along the seat track. The prevalence of real-world injuries to occupants seated at these

[20] Draft seating procedures may be found in the docket for this notice.
[21] Forward-mid is defined as the seat track position that is halfway between forward-most and mid-track (middle), while rear-mid is defined as the seat track position between the mid-track and rear-most.

positions, along with research indicating that higher chest deflections may be seen for occupants seated at the mid-track position,[22] indicate there may be an opportunity for safety gains for NCAP to test vehicles with the right front passenger ATD in the mid-track position.

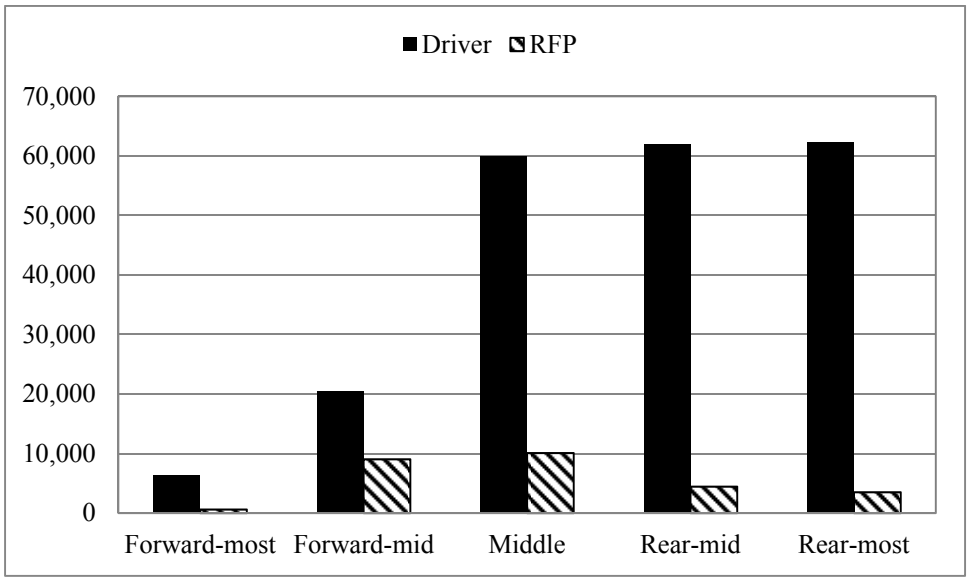

Figure 3. Number of MAIS 2+ injured occupants by seat track location in full frontal crashes.
Source: NASS-CDS (2000-2013)

As such, the agency is seeking comment on the appropriateness of potentially seating the right front passenger HIII-5F dummy in a position that is closer to (or at) the mid-track location. NHTSA plans to conduct research using the NCAP procedure but with the HIII-5F seated in the mid-track location instead. The agency believes this choice in seating location could also allow NCAP's testing to serve as a compliment to the forward-most seating location used in FMVSS No. 208.[23] NHTSA included a draft procedure for seating the HIII-5F ATD in the mid-track location in the docket of this RFC notice. The agency also included a draft procedure for seating the same ATD in the row behind the right front passenger, but this very closely follows the

[22] Tylko, S., and Bussières, A. "Responses of the Hybrid III 5th Female and 10-year-old ATD Seated in the Rear Seats of Passenger Vehicles in Frontal Crash Tests." IRCOBI Conference 2012, Paper IRC-12-65.
[23] See 65 FR 30680. Docket No. NHTSA 00-7013 Notice 1. Available at https://federalregister.gov/a/00-11577.

seating procedure for the current 5th percentile rear passenger dummy in the side moveable deformable barrier (MDB) NCAP test, the SID-IIs.[24]

3. Frontal Oblique Test

As stated previously, NHTSA published a report in 2009 examining why occupant fatalities are still occurring for belted occupants in air bag-equipped vehicles involved in frontal crashes.[25] Around this time, the agency initiated research to develop both small overlap and oblique test procedures.[26]

To establish a baseline for testing, NHTSA initiated research by conducting a series of full-scale vehicle-to-vehicle tests to understand occupant kinematics and vehicle interactions. The agency then conducted barrier-to-vehicle tests using the MDB already in use in FMVSS No. 214. These tests failed to produce the results seen in the vehicle-to-vehicle tests, which prompted NHTSA to develop a more appropriate barrier to use with the frontal oblique test configuration.[27]

The resulting modified version of the FMVSS No. 214 MDB is called the Oblique Moving Deformable Barrier (OMDB). Some differences between the OMDB and the FMVSS No. 214 MDB are that the OMDB has a face plate wider than the barrier outer track width, a suspension to prevent bouncing at high speeds, and an optimized barrier honeycomb depth and stiffness.[28] The OMDB was optimized to produce target vehicle crush patterns similar to real-world cases while minimizing the likelihood of the rigid face plate contacting the target vehicle

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[24] "U.S. Department of Transportation National Highway Traffic Safety Administration Laboratory Test Procedure for the New Car Assessment Program Side Impact Moving Deformable Barrier Test," Docket No. NHTSA-2015-0046, September 2013.
[25] National Highway Traffic Safety Administration, "Fatalities in Frontal Crashes Despite Seat Belts and Air Bags," DOT HS 811 202, September 2009.
[26] Saunders, J., Craig, M., Parent, D., "Moving Deformable Barrier Test Procedure for Evaluating Small Overlap/Oblique Crashes," SAE Int. J. Commer. Veh. 5(1):2012, doi:10.4271/2012-01-0577.
[27] Saunders, J., Craig, M.J., Suway, J., "NHTSA's Test Procedure Evaluations for Small Overlap/Oblique Crashes," The 22nd International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 11-0343, 2011.
[28] Ibid.

due to honeycomb bottoming-out.[29] It is heavier than the FMVSS No. 214 MDB at a weight of 2,486 kilograms (kg) (5,480 pounds (lb)).

Per NHTSA's current frontal oblique testing protocol, the OMDB impacts a stationary vehicle at a speed of 90 km/h (56 mph).[30] This vehicle is placed at a 15-degree angle and a 35-percent overlap occurs between the OMDB and the front end of the struck vehicle. The selected test condition was shown to be representative of a midsize vehicle-to-vehicle 15-degree oblique, 50-percent overlap test, resulting in a 56 km/h (35 mph) delta-V. When a midsize vehicle is exposed to the OMDB test condition it creates a longitudinal delta-V of about 56 km/h (35 mph). The test speed was selected to be analogous with the current severity of the NCAP full width frontal rigid barrier test of a midsize vehicle.[31] The agency has published the results of the frontal oblique test program several times over the past few years in public forums.[32] [33] In Saunders (2013), NHTSA also demonstrated the frontal oblique test protocol's repeatability. Generally, the results of this research have shown good agreement with the agency's continued examination of this particular frontal crash problem and the injuries and fatalities it causes. The fatalities and injuries caused by this crash scenario were surveyed at length in Rudd's 2011 analysis of field data from both the NASS-CDS and CIREN databases.[34] The findings discussed in Rudd (2011) as well as the NASS-CDS analysis presented earlier demonstrate that there are real-world

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[29] Ibid.
[30] Drawing package available in the docket for this notice.
[31] Saunders, J., Craig, M.J., Suway, J., "NHTSA's Test Procedure Evaluations For Small Overlap/Oblique Crashes," 22nd ESV Conference, Paper No. 11-0343, 2011.
[32] Saunders, J. and Parent, D., "Repeatability of a Small Overlap and an Oblique Moving Deformable Barrier Test Procedure," SAE World Congress, Paper No. 2013-01-0762, 2013.
[33] Saunders, J., Parent, D., Ames, E., "NHTSA Oblique Crash Test Results: Vehicle Performance and Occupant Injury risk Assessment in Vehicles with Small Overlap Countermeasures," The 24th International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 15-0108, 2015.
[34] Rudd, R., Scarboro, M., Saunders, J., "Injury Analysis of Real-World Small Overlap and Oblique Frontal Crashes," The 22nd International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 11-0384, 2011.

injuries occurring to the knee-thigh-hip, lower extremities, head, and chest. Accordingly, the agency's frontal oblique research tests predict a high probability of injury to these body regions.

NHTSA has considered existing regulations and consumer information programs, both within the agency and outside of the agency, in the development of its frontal oblique testing protocol. The most similar test mode is the Insurance Institute for Highway Safety's small overlap frontal test (IIHS-SO). The IIHS-SO test is a co-linear impact with a rigid barrier that overlaps with 25 percent of the vehicle's width, and for most vehicles does not engage the primary longitudinal structure of the front end of the vehicle. As such, the IIHS-SO test tends to drive structural countermeasures outside of the frame rails of the vehicle and strengthening of the occupant compartment.[35] The OMDB in the NHTSA frontal oblique test, in contrast, does interact with at least one frame rail of the vehicle, often resulting in a more severe crash pulse that puts greater emphasis on restraint system countermeasures. Also, because the OMDB impacts a stationary vehicle at the same speed regardless of the target vehicle's mass, the frontal oblique test protocol is a constant energy test, which allows for the comparison of test results between vehicle classes.

Recently, the agency presented its results from testing late model, high sales volume vehicles.[36] Those results indicated that many of these modern vehicles that perform well in tests conducted for other consumer information programs (including the IIHS-SO test described above) and air bags meeting FMVSS No. 226, "Ejection Mitigation," requirements may need additional design improvements to address real-world injuries and fatalities in frontal oblique

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[35] Mueller, B. C., Brethwaite, A. S., Zuby, D. S., & Nolan, J. M. (2014). Structural Design Strategies for Improved Small Overlap Crashworthiness Performance. Stapp Car Crash Journal, 58, 145.
[36] Saunders, J., Parent, D., Ames, E., "NHTSA Oblique Crash Test Results: Vehicle Performance and Occupant Injury Risk Assessment in Vehicles with Small Overlap Countermeasures," The 24th International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 15-0108, 2015.

crashes.[37] The agency intends to continue looking into the differences between the IIHS-SO and its own frontal oblique test. The observations in Saunders (2015), along with the real-world data presented previously in this document, indicate there is an opportunity to improve upon current vehicle designs in an effort to reduce fatalities and injuries in real world oblique crashes.

NCAP intends to test and rate new vehicles under a protocol very similar to the frontal oblique test protocol previously researched by the agency.[38] The program also intends to use the associated draft seating procedures for the THOR-50M ATDs in both the driver's seat and the right front passenger's seat.[39]

The potential exists for NCAP to encourage vehicles design changes that address this particular crash type. As previously noted, the occupants in Saunders (2015) showed a range of responses across several injury types.[40] This suggests that the frontal oblique test has the ability to discriminate between vehicle performances and, in turn, could allow NCAP to offer consumers comparative safety information for vehicles exposed to this crash mode.

At this time, the agency only intends to conduct left side frontal oblique impact tests in NCAP. As discussed in Appendix I, left side oblique impacts constitute a greater proportion of real-world oblique crashes. Research on both the left and right frontal oblique crash impacts is ongoing in an effort to gain a better understanding of the restraint and structural countermeasures needed to combat occupant injury in oblique impacts on both sides of vehicles.

4. Frontal Test Dummies

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[37] See 76 FR 3212. Docket No. NHTSA-2011-0004. Available at https://federalregister.gov/a/2011-547.
[38] Draft test procedure available in the docket for this notice.
[39] Draft seating procedures may be found in the docket for this notice.
[40] Saunders, J., Parent, D., Ames, E., "NHTSA Oblique Crash Test Results: Vehicle Performance and Occupant Injury Risk Assessment in Vehicles with Small Overlap Countermeasures," The 24th International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 15-0108, 2015.

a. Hybrid III 50th Percentile Male ATD (HIII-50M)

NCAP does not intend to use the HIII-50M ATD in frontal crash tests in this NCAP upgrade. This dummy is still sufficient for the needs of regulatory standards (such as FMVSS No. 208, which assesses minimal performance of vehicles with this device) and will continue to be used in that capacity. Significant advancements in vehicle safety and restraint design have taken place since the HIII-50M was incorporated into Part 572. NCAP seeks a test device that produces the most biofidelic capability and response to distinguish between the levels of occupant protection provided by modern vehicles so that manufacturers are continually challenged to design safer vehicles and consumers may be afforded the most complete and meaningful comparative safety information possible. NHTSA believes that the THOR-50M ATD has this potential. Information on the biofidelity, anthropometry, injury measurement, and other capabilities of the THOR-50M ATD is included in the section following.

b. THOR 50th Percentile Male Metric ATD (THOR-50M)

To provide consumers with the most complete and meaningful safety information possible, the agency intends to implement the THOR-50M in both frontal NCAP crash modes. The THOR-50M would be seated in the driver's seat in the full frontal rigid barrier crash test, and in both the driver's and right front passenger's seats in the frontal oblique crash test.

NHTSA currently uses the HIII-50M ATD for frontal NCAP and as one of the ATDs for compliance frontal crash testing, the latter falling under FMVSS No. 208. While the HIII-50M ATD is sufficient for the needs of regulatory standards including FMVSS No. 208, which ensure an acceptable level of safety performance has been met, NHTSA believes that a more sensitive

evaluation tool would be beneficial to help differentiate between the advancements in vehicle safety developed since the HIII-50M ATD was incorporated into Part 572 in 1986.[41] Other organizations have also announced their intentions to begin using the THOR-50M in consumer information settings. Euro NCAP indicated that it would use the THOR-50M in the development of a new offset frontal impact protection test in its 2020 Road Map published in March 2015.[42]

i. Background

NHTSA has been researching advanced ATDs since the early 1980s. The goal of this research has been to create a device that represents the responses of human occupants in modern restraint and vehicle environments. NHTSA began developing the THOR-50M around the same time that the HIII-50M was added in 49 CFR Part 572 for use in FMVSS No. 208. The THOR-50M was designed to incorporate advances in biomechanics and injury prediction that were not included in the design of the HIII-50M ATD.

NHTSA has published its work on the THOR-50M throughout its development, including the THOR Alpha,[43] THOR-NT,[44] THOR-NT with Modification Kit,[45] and THOR Metric[46] build levels. For the purposes of this RFC notice, further references to the THOR-50M indicate 472-

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[41] See 51 FR 26701. Federal Register documents published before 1993 (Volumes 1-58) are available through a Federal Depository Library.
[42] European New Car Assessment Programme, "2020 Roadmap," March 2015. [http://Euro NCAP.blob.core.windows.net/media/16472/euro-ncap-2020-roadmap-rev1-march-2015.pdf]
[43] Haffner, M., Rangarajan, N., Artis, M., Beach, D., Eppinger, R., & Shams, T., "Foundations and Elements of the NHTSA THOR Alpha ATD Design," The 17th International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 458, 2001.
[44] Shams, T., Rangarajan, N., McDonald, J., Wang, Y., Platten, G., Spade, C., Pope, P., & Haffner, M., "Development of THOR NT: Enhancement of THOR Alpha – the NHTSA Advanced Frontal Dummy," The 19th International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 05-0455, 2005.
[45] Ridella, S. & Parent, D., "Modifications to Improve the Durability, Usability, and Biofidelity of the THOR-NT Dummy," The 22nd International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 11-0312, 2011.
[46] Parent, D., Craig, M., Ridella, S., & McFadden, J., "Thoracic Biofidelity Assessment of the THOR Mod Kit ATD," The 23rd International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 13-0327, 2013.

0000 Revision F of the THOR drawing package, released on the NHTSA website in September 2015.[47] The performance of this ATD shall meet the specifications defined in the THOR-50M Qualification Procedures Manual.[48]

NHTSA has updated the public on its THOR-50M research in various forums.[49] On January 20, 2015, NHTSA held a public meeting to present further updates to its work with THOR-50M.[50] NHTSA presented draft descriptions of updated qualification procedures and data supporting the repeatability and reproducibility of the THOR-50M. During this meeting, several industry representatives took the opportunity to present their research related to the ATD. NHTSA itself has used the THOR-50M ATD extensively in testing to support both biomechanics and crashworthiness research objectives.[51]

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[47]Drawing package available in the docket for this notice.
[48] Draft qualification procedures available in the docket for this notice.
[49] Parent, D., "NHTSA THOR Update," National Highway Traffic Safety Administration, Washington, DC, September 2013. [www.nhtsa.gov/DOT/NHTSA/NVS/Biomechanics%20&%20Trauma/NHTSA_THOR_update_2013-09-30.pdf]; Parent, D., "Applications of the THOR ATD in NHTSA Research," Society of Automotive Engineers Government/Industry Meeting, January 2014. [www.nhtsa.gov/DOT/NHTSA/NVS/Public%20Meetings/SAE/2014/2014-SAE-GIM_Parent.pdf]
[50] National Highway Traffic Safety Administration, "THOR Public Meeting," January 20, 2015. [www.nhtsa.gov/Research/Biomechanics+&+Trauma/THOR+Public+Meetings]
[51] Martin, P. &Shook, L., "NHTSA's THOR-NT Database," The 20th International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 07-0289, 2007; Saunders, J., Craig, M. & Suway, J., "NHTSA's Test Procedure Evaluations for Small Overlap/Oblique Crashes," The 22nd International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 11-0343, 2011; Saunders, J., Craig, M., & Parent, D., "Moving Deformable Barrier Test Procedure for Evaluating Small Overlap/Oblique Crashes," SAE International Journal of Commercial Vehicles, 5(2012-01-0577), 172-195, 2012; Saunders, J. & Parent, D., "Repeatability of a Small Overlap and an Oblique Moving Deformable Barrier Test Procedure," SAE World Congress, paper no. 2013-01-0762, 2013; Saunders, J. & Parent, D., "Assessment of an Oblique Moving Deformable Barrier Test Procedure," The 23rd International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 13-0402, 2013; Forman, J., Michaelson, J., Kent, R., Kuppa, S., & Bostrom, O., "Occupant Restraint in the Rear Seat: ATD Responses to Standard and Pre-tensioning, Force-limiting Belt Restraints," *Annals of Advances in Automotive Medicine, 52*:141-54, Oct 2008; Hu, J., Fischer, K., & Adler, A., "Rear Seat Occupant Protection: Safety Beyond Seat Belts," Society of Automotive Engineers Government/Industry Meeting, January 2015. [www.nhtsa.gov/DOT/NHTSA/NVS/Public%20Meetings/SAE/2015/2015SAE-Saunders-AdvOccupantProtection.pdf]; Cyliax, B., Scavnicky, M., Mueller, I., Zhao, J., & Hiroshi, A., "Advanced Adaptive Restraints Program: Individualization of Occupant Safety Systems," Society of Automotive Engineers Government/Industry Meeting, January 2015. [www.nhtsa.gov/DOT/NHTSA/NVS/Public%20Meetings/SAE/2015/2015SAE-Cyliax-AARP.pdf]; Shaw, G.,

ii. THOR-50M Design

To ensure that the dummy responds in a human-like manner in a vehicle crash environment it is necessary that the size and shape of the dummy, referred to as anthropometry, provides an accurate representation of a mid-sized human. To accomplish this, a study on the Anthropometry of Motor Vehicle Occupants (AMVO) was carried out by the University of Michigan Transportation Research Institute (UMTRI) to document the anthropometry of a mid-size (50th percentile in stature and weight) male occupant in an automotive seating posture.[52 53] The AMVO anthropometry was used as a basis for the development of the THOR-50M design. The THOR-50M includes anatomically-correct designs in the neck, chest, shoulder, spine, and pelvis in order to represent the human occupant response in a frontal or frontal oblique vehicle crash environment.

The cervical neck column of the THOR-50M has a unique design. In the THOR-50M, the neck is connected to the head via three separate load paths (two cables – anterior and posterior – and a pin joint centered between the cables) versus a single path for other ATDs (a pin joint only). The biomechanical basis of the THOR-50M neck design is well established.[54 55] The construction of the THOR-50M neck allows the head to rotate relatively freely in the fore and aft

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Lessley, D., Bolton, J., & Crandall, J., "Assessment of the THOR and Hybrid III Crash Dummies: Steering Wheel Rim Impacts to the Upper Abdomen," SAE Technical Paper 2004-01-0310, 2004, doi:10.4271/2004-01-0310.

[52] Schneider, L. W., Robbins, D. H., Pflug, M. A., & Snyder, R. G., "Development of Anthropometrically Based Design Specifications for an Advanced Adult Anthropomorphic Dummy Family; Volume 1-Procedures, Summary Findings and Appendices," U.S. Department of Transportation, DOT HS 806 715, 1985.

[53] Robbins, D. H., "Development of Anthropometrically Based Design Specifications for an Advanced Adult Anthropomorphic Dummy Family; Volume 2-Anthropometric Specifications for mid-Sized Male Dummy; Volume 3- Anthropometric Specifications for Small Female and Large Male Dummies," U.S. Department of Transportation, DOT-HS-806-716 & 717, 1985.

[54] White, R. P., Zhoa, Y., Rangarajan, N., Haffner, M., Eppinger, R., & Kleinberger M. "Development of an Instrumented Biofidelic Neck for the NHTSA Advanced Frontal Test Dummy," The 15th International Technical Conference on the Enhanced Safety of Vehicles, Paper No. 96-210-W-19, 1996.

[55] Hoofman, M., van Ratingen, M., & Wismans, J., "Evaluation of the Dynamic and Kinematic Performance of the THOR Dummy: Neck Performance," Proceeding of the International Conference on the Biomechanics of Injury (IRCOBI) Conference, pp. 497-512, 1998.

directions. THOR can undergo low levels of uninjurious "nodding" without generating an appreciable moment at its pin joint. Because of this design, a THOR-specific risk curve for neck injury (discussed below) is better aligned with human injury risk at all levels of risk.

Throughout the development of the THOR-50M ATD, specific attention was given to the human-like response and injury prediction capability of the chest. The rib cage geometry is more realistic because the individual ribs are angled downward to better match the human rib orientation.[56] Performance requirements were selected to ensure human-like behavior in response to central chest impacts, oblique chest impacts, and steering rim impacts to the rib cage and upper abdomen.[57] Better chest anthropometry means that the dummy's interaction with the restraint system (as the seat belt lies over the shoulder and across the chest, for example) is more representative of the interaction humans would experience. Moreover, NHTSA has previously identified instrumentation opportunities beyond a single-point chest deflection measurement system that may improve the assessment of thoracic loading in a vehicle environment with advanced restraint technology such as air bags and pretensioners.[58] Thoracic trauma imparted to restrained occupants does not always occur at the same location on the rib cage for all occupants in all frontal crashes.[59] Kuppa and Eppinger found (in a data set consisting of 71 human subjects in various restraint systems and crash severities) that using the maximum deflection from

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[56] Kent, R., Shaw, C. G., Lessley, D. J., Crandall, J. R. & Svensson, M. Y, "Comparison of Belted Hybrid III, THOR, and Cadaver Thoracic Responses in Oblique Frontal and Full Frontal Sled Tests," Proc. SAE 2003 World Congress. Paper No. 2003-01-0160, 2003.

[57] National Highway Traffic Safety Administration, "Biomechanical Response Requirements of the THOR NHTSA Advanced Frontal Dummy, Revision 2005.1," Report No: GESAC-05-03, U.S. Department of Transportation, Washington, DC, March 2005. [www.nhtsa.gov/DOT/NHTSA/NVS/Biomechanics%20&%20Trauma/THOR-NT%20Advanced%20Crash%20Test%20Dummy/thorbio05_1.pdf]

[58] Yoganandan, N., Pintar, F., Rinaldi, J., "Evaluation of the RibEye Deflection Measurement System in the 50th Percentile Hybrid III Dummy." National Highway Traffic Safety Administration, DOT HS 811 102, March 2009.

[59] Morgan, R. M., Eppinger, R. H., Haffner, M. P., Yoganandan, N., Pintar, F. A., Sances, A., Crandall, J. R., Pilkey, W. D., Klopp, G. S., Kallieris, D., Miltner, E., Mattern, R., Kuppa, S. M., & Sharpless, C. L., "Thoracic Trauma Assessment Formulations for Restrained Drivers in Simulated Frontal Impacts," Proc. 38th Stapp Car Crash Conference, pp. 15-34. Society of Automotive Engineers, Warrendale, PA., 1994.

multiple measurement locations on the chest resulted in improved injury prediction.[60] The THOR-50M ATD is capable of measuring three-dimensional deflections at four different locations on the rib cage. This instrumentation, coupled with its thoracic biofidelity,[61] provides the THOR-50M ATD with the ability to better predict thoracic injuries and to potentially drive more appropriate restraint system countermeasures.

The THOR-50M shoulder was developed to allow a human-like range of motion and includes a clavicle linkage intended to better represent the human shoulder interaction with shoulder belt restraints.[62] The spine of the THOR-50M ATD has two flexible elements, one in the thoracic spine and one in the lumbar spine, which are intended to allow human-like spinal kinematics in both frontal and oblique loading conditions.[63] The pelvis was designed to represent human pelvis bone structure to better represent lap belt interaction,[64] [65] and the pelvis flesh was designed to represent uncompressed geometry to allow human-like interaction of the pelvis flesh with the vehicle seat.[66]

THOR-50M ATD has instrumentation that can be used to predict injury risk to the head, neck, thorax, abdomen, pelvis, upper leg, and lower leg. Coupled with improved biofidelity in

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[60] Kuppa, S., & Eppinger, R., "Development of an Improved Thoracic Injury Criterion," Proceedings of the 42nd Stapp Car Crash Conference, SAE No. 983153, 1998.
[61] Parent, D., Craig, M., Ridella, S., & McFadden, J. "Thoracic Biofidelity Assessment of the THOR Mod Kit ATD," The 23rd Enhanced Safety of Vehicles Conference, Paper No. 13-0327, 2013.
[62] Törnvall, F. V., Holmqvist, K., Davidsson, J., Svensson, M. Y., HÅland, Y., & Öhrn, H., "A New THOR Shoulder Design: A Comparison with Volunteers, the Hybrid III, and THOR NT," Traffic Injury Prevention, 8:2, 205-215, 2007.
[63] Haffner, M., Rangarajan, N., Artis, M., Beach, D., Eppinger, R., & Shams, T., "Foundations and Elements of the NHTSA THOR Alpha ATD Design," The 17th International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 458, 2001.
[64] Reynolds, H., Snow, C., & Young, J., "Spatial Geometry of the Human Pelvis," U.S. Department of Transportation, Technical Report No. FAA-AM-82-9, 1982.
[65] Haffner, M., Rangarajan, N., Artis, M., Beach, D., Eppinger, R., & Shams, T., "Foundations and Elements of the NHTSA THOR Alpha ATD Design," The 17th International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 458, 2001.
[66] Shams, T., Rangarajan, N., McDonald, J., Wang, Y., Platten, G., Spade, C., Pope, P., & Haffner, M., "Development of THOR NT: Enhancement of THOR Alpha – the NHTSA Advanced Frontal Dummy," The 19th International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 05-0455, 2005.

these areas, THOR-50M ATD has the potential to measure meaningful and appropriate sources of injury, especially in offset or oblique loading scenarios.

Evidence of the ability of the THOR-50M ATD to simulate occupant kinematics and predict injury risk has been demonstrated through a combination of field studies and fleet testing in the oblique crash test mode. NHTSA conducted two field studies to examine the sources of injury and fatality in small overlap and oblique crashes using the Crash Injury Research and Engineering Network (CIREN) and NASS-CDS databases.[67] [68] The body regions that showed the highest average injury risk as predicted by the THOR-50M ATD in fleet testing were also those regions that showed the highest incidence of injury in the 2011 field study by Rudd et al.:[69] knee-thigh-hip, lower extremity, head, and chest. Head and chest contacts observed in the fleet testing generally aligned with the sources of the most severe injuries indicated in the 2013 field study by Rudd. A majority of the fatalities in the field study were sourced to the head or chest, body regions which were also predicted to have a high risk of AIS 3+ injury in fleet testing. Additionally, Rudd (2011) observed that over half of the pelvis injuries occurred in the absence of a femur shaft fracture, which was mirrored in the fleet testing in that the average risk of acetabulum fracture was higher than the average risk of femur fracture.

Because of its improved biofidelity and injury prediction capabilities, the THOR-50M ATD is more sensitive to the performance of different restraint systems. In a study of belt-only, force-limited belt plus air bag, and reduced force force-limited belt plus air bag restraint

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[67] Rudd, R., Scarboro, M., & Saunders, J., "Injury Analysis of Real-World Small Overlap and Oblique Frontal Crashes," The 22nd International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 11-0384, 2011.
[68] Rudd, R., "Characteristics of Injuries in Fatally Injured Restrained Occupants in Frontal Crashes," The 23rd International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 13-0349, 2013.
[69] Saunders, J., Craig, M., & Parent, D., "Moving Deformable Barrier Test Procedure for Evaluating Small Overlap/Oblique Crashes," SAE International Journal of Commercial Vehicles, 5(2012-01-0577), 172-195, 2012

conditions in a frontal impact sled test series, the THOR-50M was able to differentiate between both crash severity and restraint performance.[70]

iii. Injury Criteria and Risk Curves

To assess injury in any crash test that the THOR-50M ATD is used in, NCAP intends to use many of the injury criteria and risk curves that have been used in NHTSA research testing as previously published,[71] with some modifications. These preliminary injury criteria and risk curves are described below and summarized in Appendix II of this document. The agency is seeking comment on all aspects of the following:

HEAD – NHTSA intends to use the head injury criterion (HIC_{15}) as a metric for assessing head injury risk in frontal crashes. It is currently in use in FMVSS No. 208 and frontal NCAP tests.[72] [73] As described in the 2008 NCAP Final Decision Notice, the risk curve associated with HIC_{15} in frontal NCAP testing represents a risk of AIS 3+ injury. However, while HIC_{15} injury assessment values in frontal NCAP testing have continued to decrease over time as have the field incidence of skull and facial fractures, the incidence of traumatic brain injury in frontal crashes has not decreased at a similar rate.[74] This may be because the HIC_{15} criterion only addresses linear acceleration of the head, which does not completely describe the motion of and

[70] Sunnevång, C., Hynd, D., Carroll, J., & Dahlgren, M., "Comparison of the THORAX Demonstrator and HIII Sensitivity to Crash Severity and Occupant Restraint Variation," Proceedings of the 2014 IRCOBI Conference, Paper No. IRC-14-42, 2014.
[71] Saunders, J., Parent, D., & Ames, E., "NHTSA Oblique Crash Test Results: Vehicle Performance and Occupant Injury Risk Assessment in Vehicles with Small Overlap Countermeasures," The 24th International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 15-0108, 2015.
[72] Eppinger, R., Sun, E., Bandak, F., Haffner, M., Khaewpong, N., Maltese, M., & Saul, R., "Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems II," NHTSA Docket No. NHTSA–1999–6407–5, 1999.
[73] See 73 FR 40016. Docket No. NHTSA-2006-26555. Available at https://federalregister.gov/a/E8-15620
[74] Takhounts, E. G., Hasija, V., Moorhouse, K., McFadden, J., & Craig, M., "Development of Brain Injury Criteria (BrIC)", Proceedings of the 57th Stapp Car Crash Conference, Orlando, FL, November 2013.

subsequent injury risk to the brain. To assess the risk of brain injury due to rotation of the head, Takhounts (2013) developed a kinematically based brain injury criterion (BrIC). BrIC is calculated by combining the angular velocities of the head about its three local axes compared to directionally dependent critical values. BrIC was one of many brain injury correlates that were considered and was found to have the highest correlation to two strain metrics measured in the brain. These strain metrics, cumulative strain and maximum principal strain, are the mechanical measures that have been shown to be directly associated with brain injury potential.[75]

NECK – NHTSA intends to use a modified, THOR-specific version of the neck injury criterion (Nij) as a metric for assessing neck injury in frontal crashes. Two approaches are being considered to address this difference:

a) Update Nij critical values. The formulation of Nij would be retained, but the critical values would be updated to specifically represent the THOR-50M ATD. In a presentation to the Society of Automotive Engineers (SAE) THOR Evaluation Task Group, Nightingale et al. proposed critical values for the THOR ATD based on age-adjusted post-mortem human surrogate cervical spine tolerance data.[76] These critical values were based on measurements from the upper neck load cell alone: 2520 N in tension, 3640 N in compression, 48 Nm in flexion, and 72 Nm in extension. Dibb et al. recognized this as

[75] Takhounts, E., Eppinger, R., Campbell, J., Tannous, R., Power, Erik., & Shook, L., "On the Development of the SIMon Finite Element Head Model." Stapp Car Crash Journal, Vol. 47 (October 2003), pp. 107-33.; Takhounts, E., Ridella, R., Hasija, V., Tannous, R., Campbell, J., Malone, D., Danelson, K., Stitzel, J., Rowson, S., & Duma, S., "Investigation of Traumatic Brain Injuries Using the Next Generation of Simulated Injury Monitor (SIMon) Finite Element Head Model," Stapp Car Crash Journal, Vol. 52 (November 2008), pp1-31.

[76] Nightingale, R., Ono, K., Pintar, F., Yoganandan, N., & Martin, P., "THOR Head and Neck IARVs," SAE THOR Evaluation Task Group, 2009.

a conservative estimate of injury risk because it did not account for additional resistance to tension provided by neck musculature.[77]

b) Implement a THOR-specific injury criterion. NHTSA has conducted research to evaluate the neck of the THOR-50M ATD head and neck in a wide array of loading conditions. These data would be used to develop a cervical osteoligamentous spine injury criterion (Cervical Nij or CNij).

CHEST – NHTSA intends to use one or more multi-point thoracic injury criteria to predict chest injury. A relationship between chest deformation and injury risk was determined through a series of matched-pair sled tests conducted at the University of Virginia.[78] Sled tests were conducted in 12 conditions using the THOR-50M ATD, for which thoracic biofidelity has been demonstrated (Parent, 2013). The matched set of post-mortem human surrogate (PMHS) tests included 38 observations on 34 PMHS (four PMHS were subjected to a low-speed, non-injurious loading condition before injurious testing). Incidence of injury was quantified as AIS 3+ thoracic injury to the PMHS, which represents three or more fractured ribs based on the 2005 (update 2008) version of AIS. Using the peak resultant deflection, measured at the maximum of the four thoracic measurement locations on the THOR-50M rib cage, and the incidence of PMHS injury in same test condition,[79] an injury risk function was developed.

ABDOMEN – NHTSA intends to use a measurement based on percent compression to predict abdominal injury. This is a new area for NHTSA, because THOR is the first frontal ATD

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[77] Dibb, A., Nightingale, R., Chauncey, V., Fronheiser, L., Tran, L., Ottaviano, D., & Myers B., "Comparative Structural Neck Responses of the THOR-NT, Hybrid III, and Human in Combined Tension-Bending and Pure Bending," Stapp Car Crash Journal, 50: 567-581, 2006.

[78] Crandall, J., "Injury Criteria Development: THOR Metric SD-3 Shoulder Advanced Frontal Crash Test Dummy," NHTSA Biomechanics Database, Report b11117-1, September 2013.

[79] Saunders, J., Parent, D., & Ames, E., "NHTSA Oblique Crash Test Results: Vehicle Performance and Occupant Injury Risk Assessment in Vehicles with Small Overlap Countermeasures," The 24th International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 15-0108, 2015.

to potentially be used in consumer information testing that measures dynamic abdominal deflection. Kent et al. examined several predictors of abdominal injury using a porcine surrogate, and found percent compression to be the best injury discriminator out of the considered metrics.[80] A risk function was developed to relate the percent compression to the risk of AIS 3+ abdominal injury. Percent compression can be measured on the THOR-50M ATD by dividing the maximum of the left and right peak abdominal deflection measurements by the undeformed depth of the abdomen measured at the IR-TRACC attachment points, or 238.4 millimeters (mm) (9.4 inches (in)).

PELVIS – NHTSA intends to use an acetabulum load criteria to assess potential pelvis injuries with the THOR ATD. Rudd 2011 demonstrated that pelvis injuries have been shown to occur in the absence of femur fractures, and as shown in Martin (2011), the THOR-50M ATD is able to measure the load at the interface between the greater trochanter and the acetabulum to assess the risk of these types of injuries. Rupp et al. (2009) developed a post-mortem human surrogate injury risk function to relate the force transmitted to the hip, the stature of the occupant, the hip flexion angle, and the hip abduction angle to the risk of a hip fracture.[81] To relate this risk function to the THOR-50M ATD, three substitutions are made. First, an occupant stature of 178 centimeters (70 inches) is used to represent a 50th percentile male occupant. Second, since the THOR cannot record dynamic hip angles, the hip angles are estimated to represent the typical posture at the time of peak femur load in full frontal crashes (30 degrees of flexion and 15 degrees of abduction). Third, the force measured at the THOR acetabulum must

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[80] Kent, R., Stacey, S., Kindig, M., Woods, W., Evans, J., Rouhana, S., Higuchi, K., Tanji, H., St. Lawrence, S., & Arbogast, K., "Biomechanical Response of the Pediatric Abdomen, Part 2: Injuries and Their Correlation with Engineering Parameters," Stapp Car Crash Journal, Vol. 52, November 2008.

[81] Rupp, J. D., Flannagan, C. A., & Kuppa, S. M., "Development of an injury risk curve for the hip for use in frontal impact crash testing," Journal of Biomechanics 34(3):527-531, 2010.

be related to the force measured at the hip of the post-mortem human surrogates used to develop the risk function. Martin et al. (2011) demonstrated that a scaling ratio of 1.3 could be used to relate the acetabulum force measured by THOR-NT to the PMHS acetabulum force.[82] However, this scaling ratio may not be appropriate for the THOR-50M ATD because the biofidelity of the femur was updated in the Modification Kit.[83]

UPPER LEG – NHTSA intends to use peak femur axial force as a metric for assessing femur injury risk in frontal crashes. It is currently used in FMVSS No. 208 and frontal NCAP. The THOR-50M ATD includes a femur compressive element that allows for a human-like response under axial compression.[84] Thus, the human injury risk function to relate axial femur force to risk of AIS 2+ and 3+ injury can be used directly.[85]

LOWER LEG – NHTSA intends to use injury risk curves developed for the human lower extremity and applied to the lower extremity hardware of the THOR-50M ATD.[86] [87] NHTSA developed injury risk curves for the prediction of tibia plateau fractures using the axial force measured by the upper tibia load cell; tibia/fibula shaft fractures using the Revised Tibia Index calculated using measurements from the upper and lower tibia load cells; calcaneus, talus, ankle, and midfoot fractures using the axial force measured by the lower tibia load cell; and

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[82] Martin, P. G. & Scarboro, M., "THOR-NT: Hip Injury Potential in Narrow Offset and Oblique Frontal Crashes," The 22nd International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 11-0234, 2011.
[83] Ridella, S. &Parent, D., "Modifications to Improve the Durability, Usability, and Biofidelity of the THOR-NT Dummy," The 22nd International Technical Conference for the Enhanced Safety of Vehicles Conference, Paper No. 11-0312, 2011.
[84] Ridella, S. & Parent, D., "Modifications to Improve the Durability, Usability, and Biofidelity of the THOR-NT Dummy," The 22nd International Technical Conference for the Enhanced Safety of Vehicles Conference, Paper No. 11-0312, 2011.
[85] Kuppa, S., Wang, J., Haffner, M., & Eppinger, R., "Lower Extremity Injuries and Associated Injury Criteria," The 17th International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 457, 2001.
[86] Ibid.
[87] Kuppa, S., Haffner, M., Eppinger, R., & Saunders, J., "Lower Extremity Response And Trauma Assessment Using The THOR-Lx/HIIIr And The Denton Leg In Frontal Offset Vehicle Crashes," The 17th International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 456, 2001.

malleolar fractures and ankle ligament injuries using the rotation measured by the ankle potentiometer or calculated ankle moment.

c. Hybrid III 5th Percentile Female ATD (HIII-5F) w/RibEye™

NHTSA is considering updating the HIII-5F ATD currently used in frontal NCAP with new RibEye™ instrumentation for measuring chest deflection. The background and detail for this consideration are explained below.

The HIII-5F ATD was initially developed in 1988 by a collaboration among First Technology Safety Systems and the SAE Biomechanics Subcommittees, the Centers for Disease Control and Prevention (CDC), and the Ohio State University.[88] Several updates were made to the device through the late 1980s and 1990s to improve its ability to interact with modern restraints.[89]

NHTSA's regulatory use of the HIII-5F ATD began in 1996 when the agency announced its comprehensive plan for reducing the dangers to vehicle occupants from deploying frontal air bags.[90] The agency was also required to respond to section 7103 of the Transportation Equity Act for the 21st Century (TEA21) enacted in 1998.[91] These directives resulted in the issuance of a final rule in 2000 that required advanced air bag protection for a variety of occupant sizes, including smaller persons represented by the HIII-5F ATD.[92] That rulemaking was the first requiring vehicle manufacturers to certify their products to the occupant crash protection standard, FMVSS No. 208, using the small female dummy in dynamic vehicle tests (both belted

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[88] Humanetics Innovative Solutions, "Hybrid III 5th Female Dummy - 880105-000-H," August 2015. [www.humaneticsatd.com/crash-test-dummies/frontal-impact/hybrid-iii-5th]
[89] Ibid.
[90] National Highway Traffic Safety Administration. (November 22, 1996). NHTSA Announces Comprehensive Plan to Improve Air Bag Technology and Reduce Air Bag Dangers [Press Release]. Retrieved from http://stnw.nhtsa.gov/nhtsa/announce/press/PressDisplay.cfm?year=1996&filename=pr112296a.html
[91] "Transportation Equity Act for the 21st Century," Pub. L. No. 105–178, sec. 7103, 112 Stat. 107 (June 9, 1998).
[92] See 65 FR 30680. Docket No. NHTSA 00-7013 Notice 1. Available at https://federalregister.gov/a/00-11577.

and unbelted). In MY 2011 vehicles, the agency began testing with the HIII-5F ATD in the right front passenger's seat of NCAP's 56 km/h (35 mph) full frontal rigid barrier test.[93]

In recent studies using data from the FARS and NASS-CDS databases, researchers have found that in a comparable crash, belted females have higher risk of injury and death overall than belted males, as well as higher chest injury risk specifically.[94] Differing injury patterns between males and females also suggest differences in restraint interaction and effectiveness. For example, using NASS-CDS data from 1997 to 2011, Parenteau et al. (2013) showed that females have higher risk of belt- and air bag-sourced chest injuries.[95] NHTSA also found that females had a higher percentage of injuries sourced to the air bag in frontal collisions.[96] Thus, it remains important to assess the risk of injury to smaller female occupants using the currently available HIII-5F ATD.

Similar to what was discussed above for the THOR-50M, the agency has identified an opportunity to improve on the type of thoracic injury data it collects when using the HIII-5F ATD in full frontal NCAP tests. In an effort to improve the quality of thoracic deflection measurements collected by ATDs, Boxboro Systems developed a set of optical thoracic

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[93] See 73 FR 40016. Docket No. NHTSA-2006-26555. Available at https://federalregister.gov/a/E8-15620; Also see 73 FR 79206. Docket No. NHTSA-2006-26555. https://federalregister.gov/a/E8-30701.

[94] Bose D., Segui-Gomez, M., & Crandall J. "Vulnerability of Female Drivers Involved in Motor Vehicle Crashes: An Analysis of US Population at Risk," American Journal of Public Health 101(12):2368-2373, 2011; Parenteau, C. S., Zuby, D., Brolin, K. B., et al. "Restrained male and female occupants in frontal crashes: Are we different?" Proceedings of the International Research Council on Biomechanics of Injury (IRCOBI) Conference. Paper IRC-13-98, 2013; Kahane, C. J. "Injury vulnerability and effectiveness of occupant protection technologies for older occupants and women". National Highway Traffic Safety Administration. Report No. DOT HS 811 766, 2013.

[95] Parenteau, C. S., Zuby, D., Brolin, K. B., et al. "Restrained male and female occupants in frontal crashes: Are we different?" Proceedings of the International Research Council on Biomechanics of Injury (IRCOBI) Conference. Paper IRC-13-98, 2013.

[96] Kahane, C. J. "Injury vulnerability and effectiveness of occupant protection technologies for older occupants and women". National Highway Traffic Safety Administration. Report No. DOT HS 811 766, 2013.

instrumentation known as the RibEye™.[97] The RibEye™ system is comprised of up to 12 light emitting diodes (LEDs) which are mounted internally to the ribs of the dummy. Two detectors that allow the system to measure deflections in both the x- and y-directions receive light from the LEDs. One advantage that the RibEye™ system has over traditional single-point potentiometers is the ability to assess asymmetric loading of the thorax rather than just a one dimensional deflection at the sternum.[98]

The agency intends to conduct further research on the HIII-5F ATD with the RibEye™ instrumentation. Research findings indicate that the multi-point thoracic deflection measurement capability of the RibEye™ system has the potential to record higher and potentially more meaningful (with respect to the effects of belt routing) chest deflections than a single potentiometer at the sternum.[99] The agency intends to evaluate its merit in discriminating the multi-point thoracic deflection measurement capability of the RibEye™ amongst vehicle performance in the full frontal NCAP environment.

NHTSA has previously acknowledged that there is a need for greater understanding of the rear seat environment.[100] In a double-paired comparison study using FARS data, NHTSA research indicated that restrained occupants older than 50 years were protected better in the front row than in the rear row.[101] A follow-up parametric study indicated that while there are many

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[97] Handman, D. "Multi-point position measuring and recording system for anthropomorphic test devices." U.S. Patent Number 7508530B1. 24 March 2009.
[98] Yoganandan, N., Pintar, F., Rinaldi, J., "Evaluation of the RibEye Deflection Measurement System in the 50th Percentile Hybrid III Dummy." National Highway Traffic Safety Administration, DOT HS 811 102, March 2009.
[99] Eggers, A. & Adolph, T., "Evaluation of the Thoracic Measurement System 'RibEye' in the Hybrid III 50% in Frontal Sled Tests," The 22nd Enhanced Safety of Vehicles Conference, Paper Number 11-0190, 2011; Eggers, A., Eickhoff, B., Dobberstein, J., Zellmer, H., & Adolph, T., "Effects of Variations in Belt Geometry, Double Pretensioning and Adaptive Load Limiting on Advanced Chest Measurements of THOR and Hybrid III," IRCOBI Conference, IRC-14-40, 2014.
[100] See 78 FR 20597. Docket No. NHTSA-2012-0180. Available at https://federalregister.gov/a/2013-07766
[101] Kuppa, S., Saunders, J., & Fessahaie, O., "Rear Seat Occupant Protection in Frontal Crashes," The 19th Enhanced Safety of Vehicles Conference, Paper No. 05-0212, 2005.

design challenges that must be considered, certain rear seat occupants could benefit from the addition of advanced restraint technology like pretensioners and load limiters.[102] NHTSA has continued its study of potential restraint countermeasures for the rear seat vehicle environment through research initiatives.[103] While both occupancy and injury rates for the rear seat are low when compared to the front seat, there may be an opportunity in NCAP to better understand the needs of rear seat occupants, especially in consideration of modern vehicles that are lighter and more compact than their predecessors.

Accordingly, the agency intends to conduct research tests with a HIII-5F dummy in the rear seat of full frontal tests to determine whether or not to include this ATD in the rear seat of full frontal NCAP tests. Including testing of an ATD in the rear seat of full frontal tests would be consistent with the testing done in other international vehicle safety consumer information programs such as Euro NCAP and Japan NCAP.[104]

NHTSA is also undertaking research efforts to procure and evaluate a 5th percentile female version of the THOR ATD.[105] NHTSA expects to acquire several of these devices and conduct testing using them within the next few years. A 5th percentile female THOR ATD would have instrumentation that is similar to the THOR-50M ATD, including many improved

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[102] Kent, R., Forman, J., Parent, D., & Kuppa, S., "Rear Seat Occupant Protection in Frontal Crashes and its Feasibility," The 20th Enhanced Safety of Vehicles Conference, Paper No. 07-0386, 2007.
[103] Hu, J., & Saunders, J. "Rear Seat Occupant Protection: Safety Beyond Seat Belts." SAE Government/Industry Meeting, January 21, 2015. Available at www.nhtsa.gov/DOT/NHTSA/NVS/Public%20Meetings/SAE/2015/2015SAE-Saunders-AdvOccupantProtection.pdf.
[104] European New Car Assessment Programme, "Full Width Frontal Impact Test Protocol," Version 1.0.1, April 2015. [http://euroncap.blob.core.windows.net/media/17000/euro-ncap-frontal-fw-test-protocol-v101-april-2015.pdf]; European New Car Assessment Programme, "Assessment Protocol – Adult Occupant Protection," Version 7.0.2, April 2015. [http://euroncap.blob.core.windows.net/media/16999/euro-ncap-assessment-protocol-aop-v702-april-2015.pdf]; Japan NCAP, "Collision Safety Performance Tests," Accessed August 18, 2015. [www.nasva.go.jp/mamoru/en/assessment_car/crackup_measure.html]
[105] National Highway Traffic Safety Administration, "THOR 5th Female ATD." Accessed August 17, 2015.

measurement capabilities like multi-point chest and abdominal deflections.[106] Its biofidelity and kinematics are expected to be an improvement compared to the HIII-5F ATD, especially in the context of rear seat frontal impact testing. At this time, the THOR 5th has not been refined to a full production level, so it is not yet a candidate for consideration over the HIII-5F in frontal NCAP tests. Thus, the agency intends to use the HIII-5F ATD in this NCAP upgrade. It also intends to use the formulae and risk curves presented in Appendix III of this document to assess the injury risk to this size occupant.

Though three modes of potential neck injury are assessed for the HIII-5F dummy, the maximum neck injury potentials for both dummies under the current frontal NCAP have all resulted from the calculation of Nij.[107] The Nij criterion has been used to assess injury in frontal crashes conducted by the agency both in a regulatory context and in frontal NCAP since the 2011 model year.[108] NCAP has seen a general decline in HIII-5F ATD Nij values, which has helped result in higher right front passenger star ratings.[109]

The current Nij risk function used in NCAP with HIII-5F ATD produces a risk value of 3.8 percent when Nij equals zero. To address this, two corrections have been made to generate

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[106] Ebert, S. & Reed, M., "Anthropometric Evaluation of THOR-05F." National Highway Traffic Safety Administration, UMTRI-2013-12, April 2013; Shams, T., Huang, T.J., Rangarajan, N., Haffner, M., "Design Requirements for a Fifth Percentile Female Version of the THOR ATD," The 18th Enhanced Safety of Vehicles Conference, Paper Number 421, 2003.

[107] Park, B., Rockwell, T., Collins, L., Smith, C., Aram, M., "The Enhanced U.S. NCAP: Five Years Later," The 24th International Technical Conference for the Enhanced Safety of Vehicles Conference, Paper Number 15-0314, 2015.

[108] Eppinger, R., Sun, E., Bandak, F., Haffner, M., Khaewpong, N., Maltese, M., Saul, R., "Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems II," NHTSA Docket No. NHTSA–1999–6407–5, 1999.

[109] Park, B., Rockwell, T., Collins, L., Smith, C., Aram, M., "The Enhanced U.S. NCAP: Five Years Later," The 24th International Technical Conference for the Enhanced Safety of Vehicles Conference, Paper Number 15-0314, 2015.

the HIII-5F Nij risk curve being included in this notice. First, revised Nij experimental data[110] were used. Second, given the updated Nij values and paired injury outcomes, survival analysis with a Weibull distribution was used produce an AIS 3+ risk curve that passes through 0.0% for Nij equal to zero.

B. Side Crashworthiness

1. Real-World Side Crash Data

In support of this RFC notice, a review of 10 years' worth (2004-2013) of National Automotive Sampling System – Crashworthiness Data System (NASS-CDS) data was conducted to understand side impact crashes in the real world. For light vehicles in this analysis, crashes must have been representative of those covered by the current FMVSS No. 214; that is, (1) they must have involved another light vehicle or tall, narrow object such as a tree or pole; (2) the direction of the highest delta-V impact must have been between 7 and 11 o'clock for left-side impacts and between 1 and 5 o'clock for right-side impacts; and (3) the lateral delta-V must have been between 0-25 mph (0-40.2 km/hr). Only tow-away, non-rollover vehicles were included. Shallow-side (sideswipe) impacts were excluded, as were impacts with the second-highest delta-V known to be to the top of the vehicle.[111] Also excluded were impacts with the second-highest delta-V known to be to the rear, front, or undercarriage of the vehicle with a non-shallow or unknown extent of crush. At least one occupant must have received a MAIS 2+ injury or must have died within 30 days of the crash. Furthermore, at least one such injured occupant must have been seated in the front or rear rows of vehicle-to-vehicle crashes or the front row of vehicle-to-

[110] Mertz, H.J., & Prasad, P., 2000. "Improved neck injury risk curves for tension and extension moment measurements of crash dummies." Proceedings of the 44th Stapp Car Crash Conference, Atlanta, GA.

[111] Impacts with the second-highest delta-V known to be to the top of the vehicle were excluded as this ensures that injuries are sustained from the primary side impact.

pole crashes. All occupants younger than 13 in the front row or 8 in the rear row or those completely ejected from the vehicle were excluded. If an occupant sustained a head injury, it must have been to the brain, skull, scalp, or face.

All data presented for the side NCAP section is in terms of unadjusted values and has been weighted to a certain extent. The data has been weighted for frequency but not adjusted for various factors, such as recent rulemakings or increased belt use. It is critical to note that, as the final population estimates to be presented in the Final Notice will be adjusted for these factors, the estimates presented in today's RFC notice are preliminary and are subject to change.

This preliminary analysis of crashes representing FMVSS No. 214 conditions showed an estimated 9,180 side impact crashes involving light vehicles occurred annually, 371 (4%) of which involved a tree or pole and 8,809 (96%) of which involved another light vehicle. In these side impact crashes, there were an estimated 384 fatalities and 9,276 moderately-to-critically injured (AIS 2-5) occupants each year. There were an estimated 50,606 total injuries sustained yearly during the review period with each occupant sustaining, on average, about five different injuries. All fatal injuries were sustained in outboard seating positions; when excluding middle seat occupants, there were 9,229 moderately-to-critically injured occupants yearly. Further data gathered from this study will be discussed in relevant subsections later in this RFC notice.

2. Current Side NCAP Program

Since its introduction into NCAP in 1996, the side NCAP MDB test has been a staple of the program's crash-testing effort. This side test, which, except for speed, is the same as the MDB test included in FMVSS No. 214, simulates a 90-degree intersection-style crash. Test speed in the side NCAP MDB test is 61.9 km/h (38.5 mph), which is 8 km/h (5 mph) faster than the speed specified in FMVSS No. 214.

The side NCAP MDB test was last upgraded in MY 2011 to include new test dummies and advanced injury criteria. At that time, an ES-2re 50th percentile male dummy and a SID-IIs 5th percentile female dummy were chosen to replace the 50th percentile Side Impact Dummy with Hybrid III head and neck (SID-H3) in the driver's seat and rear passenger's seat, respectively. These same dummies have also been specified for use in the FMVSS No. 214 side MDB test since the 2007 Final Rule. The FMVSS No. 214 injury criteria adopted for the ES-2re dummy were to address head (HIC_{36}), chest (thoracic rib deflection), abdominal (combined abdominal force), and pelvic (pubic symphysis force) injuries. Injury criteria adopted for the SID-IIs ATD were to address head (HIC_{36}), lower spine (lower spine resultant acceleration), and pelvic (combined pelvic force) injuries. NCAP uses injury risk curves to assess the level of injury risk for rating purposes. For the ES-2re dummy, NCAP uses injury risk curves for all four body regions addressed in the regulation. NCAP uses only the head and pelvis regions for rating SID-IIs performance because there was no valid lower spine acceleration risk curve available at the time of the upgraded program.

The current side NCAP program also includes an oblique vehicle-to-pole test which was introduced in MY 2011 when the program was last upgraded.[112] Similar to the side MDB crash test, NCAP's side pole crash test was based on the FMVSS No. 214 side pole test, which was adopted into the standard in 2007.[113] This test is designed to simulate a side impact crash involving a tree or utility pole. In both the side NCAP test and the FMVSS No. 214 compliance test, the test vehicle is towed at 32 km/h (20 mph) into a rigid pole.[114] The driver dummy

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[112] See 73 FR 40016. Docket No. NHTSA-2006-26555. Available at https://federalregister.gov/a/E8-15620.
[113] See 72 FR 51908. Docket No. NHTSA-29134. Available at https://federalregister.gov/a/07-4360.
[114] FMVSS No. 214 specifies a range of speeds (26 km/h to 32 km/h, or 16 mph to 20 mph), rather than one target speed as in the side NCAP pole test.

specified for NCAP's side pole test is a 5th percentile female SID-IIs dummy, whereas both the 5th percentile female SID-IIs dummy and the 50th percentile male ES-2re dummy are specified in FMVSS No. 214.

Vehicle manufacturers have been responsive to the program changes implemented in MY 2011. A review of star rating data from NCAP's first model year of testing compared to the most recent model year (MY 2015) shows that average star ratings for the driver in the pole test, as represented by the 5th percentile SID-IIs dummy, have improved 19 percent. Average ratings for both the driver and the rear passenger in the MDB test have increased 11 percent since MY 2011. Star ratings, in general, are now quite high for side impact protection. Most vehicles achieved 5 stars in both side impact crash tests in MY 2015.

As a result, current side NCAP star ratings are reaching a point at which they are no longer providing distinct discrimination between vehicle models. To continually promote further advancements in side occupant protection, changes to the side NCAP program are once again appropriate. Accordingly, NHTSA intends to introduce a new, advanced, average-size side impact test dummy that is capable of measuring additional injuries in side impact crashes.

3. Planned Upgrade

a. Side MDB Test

Today, the agency announces its intention to once again enhance the side MDB test for the NCAP safety ratings program in light of the aforementioned limitations on discriminating vehicles and the agency's recent analysis of real-world data showing a continued need to address side impact protection. NHTSA's preliminary estimate of real-world crash data mentioned previously indicates that an estimated 8,809 side impact vehicle-to-vehicle crashes occurring

annually had at least one occupant receiving an injury of MAIS 2 or greater.[115] Each year, about 9,270 front and/or rear seat occupants received moderate-to-fatal injuries, considered to be MAIS 2 to MAIS 6. Ninety-six percent (8,922) of these occupants were seated in the front seat, and the remaining 4 percent (348) were seated in the rear. These occupants received approximately 21,595 separate AIS 2+ injuries each year. For this population, 37 percent of moderate-to-fatal injuries were to the torso, 25 percent were to the head, and 18 percent were to the pelvis.

Although the side MDB test itself will not change,[116] the new WorldSID 50th percentile male (WorldSID-50M) Standard Build Level F (SBL F) dummy will now be specified for the driver's seat instead of the 50th percentile ES-2re male dummy, which is used currently.[117] The WorldSID-50M dummy's increased biofidelity, particularly in the head, shoulder, thorax, and abdominal regions, make this dummy the best choice for evaluating these types of injuries.[118] The WorldSID-50M ATD is more sensitive to oblique loads. This will be discussed further in the WorldSID-50M ATD Biofidelity section, to be found later in this RFC notice.

The SID-IIs 5th percentile female dummy will continue to occupy the near-side rear outboard seat of the test vehicle. For small-stature occupants in the rear outboard seat of vehicle-to-vehicle crashes, 29 percent of AIS 2+ injuries were to the head, 18 percent to the pelvis, 17 percent to the chest, and 16 percent to the abdomen.[119] Fifth-percentile female dummies not only represent small occupants (including vulnerable and older occupants), but they are also appropriately sized surrogates for older children.

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[115] NHTSA's review of NASS-CDS cases; see Real-World Data section.
[116] "U.S. Department of Transportation National Highway Traffic Safety Administration Laboratory Test Procedure for New Car Assessment Program Side Impact Moving Deformable Barrier Test," Docket No. NHTSA-2015-0046, September 2013.
[117] The test will also remain applicable to those vehicles with a (GVWR) of 4,536 kg (10,000 lbs) or less.
[118] See WorldSID-50M Biofidelity section.
[119] NHTSA's review of NASS-CDS cases; see Real-World Data section.

The WorldSID 5th percentile female (WorldSID-5F) dummy is currently going through the final stages of development and robustness testing. The WorldSID-5F ATD has improved thorax and abdominal biofidelity. However, as discussed in a later section of this RFC notice, there are remaining concerns to be addressed before it can be included in the next NCAP upgrade.

b. Side Pole Test

NHTSA's real-world estimates indicate that about 371 side impact vehicle-to-pole crashes occurred annually in which the front seat occupant received an injury of MAIS 2 or greater.[120] These occupants received approximately 1,415 AIS 2+ injuries each year. While the frequency with which side pole crashes occurred is low in comparison to vehicle-to-vehicle crashes, the body regions injured tended to be different than in vehicle-to-vehicle crashes. For this population, nearly half (49%) of the moderate-to-fatal injuries were to the head, followed by injuries to the pelvis (15%), torso (14%), and lower limb (13%).

For the side oblique pole test, the agency will not alter the test itself.[121] Instead, it intends to replace the SID-IIs ATD with the WorldSID-50M ATD in the front struck-side outboard seating position. As mentioned in previous rulemakings, the distribution of injury, severity and types of injury were different in small-stature occupants compared to mid-size to larger occupants.[122] Nearly two-thirds of AIS 2+ injuries for small-stature occupants in narrow-object crashes were to the occupant's head. Other commonly injured body regions were the lower

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[120] Ibid.
[121] "U.S. Department of Transportation National Highway Traffic Safety Administration Laboratory Test Procedure for New Car Assessment Program Side Impact Rigid Pole Test," Docket No. NHTSA-2015-0046, September 2013.
[122] See 73 FR 40028. Docket No. NHTSA-2006-26555. Available at https://federalregister.gov/a/E8-15620.

extremities (12%) and pelvis (11%).[123] This differing distribution of injury was one of the reasons that the agency decided to include the SID-IIs ATD in the driver's seat of the existing NCAP oblique pole test.

However, the agency believes it is advantageous to use the most advanced tools available. The WorldSID-50M ATD is able to more accurately assess risk of injuries to occupants due to its improved biofidelity.[124] The WorldSID-50M ATD offers more realistic anthropometry and should lead to improved head protection for real-world occupants. Over four-fifths (82%) of the occupants sustaining MAIS 2+ injuries from pole or tree crashes were between 165 cm (5 ft 5 in) and 180 cm (5 ft 11 in), a size well-represented by the WorldSID-50M ATD.[125] For this population, 35 percent of the AIS 2+ injuries were to the head, 20 percent were to the pelvis, 16 percent were to the chest, and 14 percent were to the lower limbs.

NHTSA's data analysis also supports the need for testing small-stature occupants in the driver seating position. Even though mid-size to larger occupants were injured more frequently than small-stature occupants in narrow-object side impact crashes, the rationale presented in previous rulemakings for using the 5th percentile female dummy in the front near-side seat is still compelling. The side impact standard (FMVSS No. 214), ejection mitigation standard (FMVSS No. 226), and IIHS moderate and small offset frontal impact tests should encourage vehicle designs which provide adequate side impact protection for small-stature occupants' heads. Further, the agency believes the injury mitigation techniques developed for the WorldSID-50M ATD's torso, abdomen, and pelvis should benefit smaller occupants. In using the WorldSID-

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[123] NHTSA's review of NASS-CDS cases; see Real-World Data section.
[124] Biofidelity and anthropometry of this dummy will be discussed later in this RFC notice.
[125] NHTSA's review of NASS-CDS cases; see Real-World Data section.

50M in the enhanced consumer information program, the agency is taking a complementary approach by also relying on compliance testing and regulation.

c. Additional Considerations

Currently, NCAP's side test protocol specifies that the left (driver) side of the vehicle be struck by the moving barrier or pole. As part of this NCAP upgrade, NHTSA intends to exercise the option of having the side MDB and/or pole impact either the left side or right side of the vehicle, similar to FMVSS No. 214 protocol. Expanding the test applicability to cover both the left and right sides should ensure that the side impact rating includes information about the protection offered to the occupants on both sides of a vehicle. Only one crash test will be performed per vehicle and per crash type. The agency is specifically seeking comment on this amendment to the NCAP protocol.

In the 2013 request for comments, NHTSA received comment on using dummies in the non-struck side of the crash test. The agency is not considering the inclusion of far-side dummies at this time. Pilot-testing has not been conducted to determine which dummies would be most suitable, which test conditions need to be adjusted, and what types of injury data would be collected from such tests.

As part of this RFC notice, the agency is also requesting comment on a revised seating procedure for the rear seat SID-IIs dummy in the side MDB test. The current seating procedure has been amended to account for new rear seat designs.

4. Side Test Dummies

a. WorldSID 50th Percentile Male ATD (WorldSID-50M)

i. Background

The WorldSID-50M ATD is a state-of-the-art side impact dummy that was developed beginning in June 1997 under the auspices of the International Organization for Standardization (ISO) working group on Anthropomorphic Test Devices (TC22/SC12/WG5). It is part of the WorldSID family of dummies, which currently only includes the 50th percentile male and 5th percentile female. The working group's primary goal was to create a single, worldwide harmonized, mid-size male test device for side impact that had enhanced injury assessment capabilities, superior biofidelity and anthropometry, and which would eliminate the need to use different dummies in different parts of the world in regulation and other testing. This would also offer the benefit of reducing total development costs for manufacturers.

While the WorldSID-50M ATD has not been used previously in NHTSA rating programs, it is currently being used by other agencies and organizations worldwide. Euro NCAP began using WorldSID-50M ATD in both side barrier and side pole testing in 2015, and China-NCAP has committed to use it in 2018. Other consumer programs, such as Korean NCAP and ASEAN NCAP, are also considering its use, and it is being recommended as the test device in the pole side impact Global Technical Regulation (GTR) No. 14.[126] The inclusion of WorldSID-50M ATD into NCAP would further enhance harmonization, a goal supported by many of the respondents to the agency's April 2013 request for comments notice on NCAP enhancements. It also presents a strategy which is similar to that employed by Euro NCAP, whereby the WorldSID-50M ATD was added to Euro NCAP to serve as a consumer test tool prior to it being adopted into regulation (United Nations Economic Commission of Europe (ECE) R95).

Manufacturers also commented in their responses to the 2013 RFC notice that the adoption of more biofidelic dummies like the WorldSID-50M ATD will allow them to develop

[126] ECE/TRANS/180/Add.14

improved occupant protection systems and therefore reduce injury risk to the general public.[127] As will be discussed later, NHTSA has evaluated the WorldSID-50M ATD using an updated version of the NHTSA biofidelity ranking system and finds this dummy to be superior because of its improved shoulder response, improved thoracic response in both lateral and oblique directions, ability to measure abdominal displacement, and durability and repeatability.

Given the outcome of the agency's biofidelity assessment of the WorldSID-50M dummy, its injury assessment measurement capabilities, and the broad support expressed for the dummy, both through responses to the agency's 2013 Request for Comments notice and its use in other consumer programs, the agency plans to adopt the WorldSID-50M dummy in NCAP for use in the front struck-side seat in the side MDB test as well as the side oblique pole test.

ii. Anthropometry, Construction, and Material Properties

As mentioned previously, to ensure that a dummy can appropriately replicate the motion and responses of a human in a real-world crash, it is critical that the dummy's anthropometry (i.e., size and shape) accurately reflect the population it is intended to represent. Work related to WorldSID-50M ATD's anthropometry was carefully conducted to ensure this would be the final result. An anthropometrical study conducted by UMTRI served as the basis for WorldSID-50M ATD's anthropometry.[128] The study was developed with consideration given to the dummy design process and consisted of measuring actual humans in actual vehicle seats.

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[127] "New Car Assessment Program," Docket No. NHTSA-2012-0180.
[128] University of Michigan "Development of Anthropometrically Based Specifications for an Advanced Adult Anthropomorphic Dummy Family", Volume 1-2, December 1983.

According to the latest ISO documentation, the WorldSID-50M dummy stands 175 cm tall (5 ft 9 in) and weighs 74.4 kg (164.0 lb) in the suited, half-arm configuration.[129] This compares well to the average height (172 cm, or 5 ft 7 in) and weight (80.6 kg, or 177.7 lb) of front seat occupants injured in collisions with passenger vehicles and narrow objects.[130]

Similar to that mentioned for the THOR-50M dummy, the WorldSID-50M ATD's rib cage geometry is also more similar to a human's. When seated, the WorldSID-50M ATD's ribs are oriented nearly horizontally since they are angled downward like a human's when standing. Furthermore, the WorldSID-50M ATD exhibits a more anatomically correct representation of a vehicle-seated posture as its specifications were based on a study of humans in vehicle seats. The seated posture for the WorldSID-50M ATD's lumbar spine, which is designed for more human-like thorax-pelvis coupling, is more flexible. This causes the WorldSID-50M ATD to sit in a more slouched position.

The WorldSID-50M ATD's ribs, which are each designed to allow a lateral deflection of at least 75 mm (2.95 in), are made of a super-elastic nickel-titanium alloy that allows them to deflect similarly to a human's.[131] The WorldSID-50M ATD has two abdomen ribs that share the same construction, and therefore deflection behavior, as the dummy's thorax ribs. The latest build level of the WorldSID-50M ATD utilizes two-dimensional Infra-Red Telescoping Rods for Measuring Chest Compression (2D IR-TRACCs). The IR-TRACCs, which are used to measure shoulder, thoracic, and abdominal rib deflections in the WorldSID-50M ATD, measure the change in distance between the spine box and the most lateral point of the dummy's ribs.

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[129] Note that the agency is proposing to use the half-arm configuration in crash tests; the mass of this dummy when suited with full arms is 78.3 kg (172.6 lb). All dummy weights can be found in ISO Technical Specification, ISO/TS 15830-5 (revised 9-Jul-15).
[130] NHTSA's review of NASS-CDS cases; see Real-World Data section.
[131] ISO WorldSID Task Group, "About WorldSID," [www.worldsid.org/aboutworldsid.htm]. Accessed 25 Sep 2015.

Previous build levels of the WorldSID-50M ATD are equipped with one-dimensional (1D) IR-TRACCs, but these are no longer supplied with the dummy.

Instead of using the 2D IR-TRACCs, a RibEye™ system for the WorldSID-50M, available from Boxboro Systems, LLC, may be used.[132] The RibEye™ system is the same general system described earlier that NHTSA intends to use in the HIII-5F. RibEye™, used to measure shoulder, thoracic, and abdominal rib deflections, optically measures the change in distance in the X, Y, and Z directions between the spine box and appropriate points on the dummy's ribs.

iii. Biofidelity

The design and evaluation of effective occupant protection systems is dependent upon the availability of dummies and degree of biofidelity – those which are able to reliably and repeatedly predict possible human injuries. Biofidelity is a measure of how well a dummy duplicates the responses and kinematics of a human vehicle occupant during a real-world crash event. As mentioned previously, one of the WorldSID task group's main goals in developing the WorldSID-50M ATD was to create a harmonized side impact dummy having superior biofidelity. There are two main biofidelity rating systems in use today – the International Organization for Standardization Technical Report 9790 (ISO/TR9790) classification system,[133] and the Biofidelity Ranking System (BRS, or BioRank) developed by NHTSA.[134] [135] [136]

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[132] Hardware User's Manual, RibEye multi-point deflection measurement system, 3-axis version for the WorldSID 50th ATD, Boxboro Systems, LLC, February 2011.
[133] ISO/TC22/SC12/WG5, Technical Report 9790 – Road Vehicle – Anthropomorphic side impact dummy – lateral impact response requirements to assess the biofidelity of the dummy, 2000.
[134] Rhule, H. H., Maltese, M. R., Donnelly, B. R., Eppinger, R. H., Brunner, J. K., & Bolte, J. H. IV. "Development of a New Biofidelity Ranking System for Anthropomorphic Test Devices," Stapp Car Crash Journal 46: 477-512, 2002.

The ISO/TR9790 biofidelity classification system utilizes a series of drop tests, pendulum impact tests, and sled tests to determine individual biofidelity ratings for six body regions, including the head, neck, shoulder, thorax, abdomen, and pelvis.[137] Subsequently, the dummy is assigned an overall biofidelity rating, which is calculated by weighting and summing the biofidelity ratings for the individual body regions. As shown in Table 2, the scale for overall and individual body region ratings ranges from 0 (unacceptable) to 10 (excellent), with higher numbers indicating better biofidelity.

Table 2. ISO Biofidelity Classification

Excellent	> 8.6 to 10
Good	> 6.5 to 8.6
Fair	> 4.4 to 6.5
Marginal	> 2.6 to 4.4
Unacceptable	0 to 2.6

Source: ISO/TC22/SC12/WG5, Technical Report 9790 – Road Vehicle – Anthropomorphic side impact dummy – lateral impact response requirements to assess the biofidelity of the dummy, 2000.

The ISO WorldSID Task Group has used the ISO/TR9790 impact test methods and biofidelity rating scale to evaluate the WorldSID-50M ATD.[138] The overall biofidelity rating and the assessed body regions are shown in Table 3. The WorldSID-50M ATD, which received an ISO rating of 8.0, is classified as having "good" biofidelity. It also received overwhelmingly

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[135] Rhule, H., Moorhouse K., Donnelly, B., & Stricklin, J. "Comparison of WorldSID and ES-2re Biofidelity Using an Updated Biofidelity Ranking System," The 21st International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 09-0563, 2009.

[136] Rhule, H., Donnelly, B., Moorhouse, K., & Kang, Y.S. "A Methodology for Generating Objective Targets for Quantitatively Assessing the Biofidelity of Crash Test Dummies," The 23rd International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 13-0138.

[137] A set of requirements is established for each test specified for a particular body region. Dummy responses for a given test are subsequently compared against expected corridors for each requirement, and a rating for each requirement is then assigned. Ratings for the individual requirements are then weighted and summed to arrive at an overall rating for each test conducted for a particular body region. The test ratings for any one body region are then weighted and summed to assign an individual rating for the body region.

[138] Scherer, R., Bortenschlager, K., Akiyama, A., Tylko, S., Hartleib, M., and Harigae, T., "WorldSID Production Dummy Biomechanical Responses," The 21st International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 09-0505, 2009.

positive ratings for each body region. In fact, head, shoulder, and abdominal biofidelity were rated "excellent", and thoracic biofidelity was rated "good." Neck and pelvis biofidelity were rated "fair". Such localized biofidelity is as equally important as overall biofidelity as this allows vehicle safety engineers to optimize vehicle designs and enhance occupant protection in side impact crashes.

Table 3. WorldSID 50th Percentile Male Side Impact Dummy Biofidelity– ISO Ratings

	Head	Neck	Shoulder	Thorax	Abdomen	Pelvis	Overall
WorldSID	10	5.3	10	8.2	9.3	5.1	8.0

Source: Scherer, R., Bortenschlager, K., Akiyama, A., Tylko, S., Hartleib, M., and Harigae, T., "WorldSID Production Dummy Biomechanical Responses," The 21st International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 09-0505, 2009.

NHTSA has performed its own biofidelity evaluation of the WorldSID-50M ATD using the Biofidelity Ranking system.[139] Like the ISO/TR9790 biofidelity classification system, this system uses pendulum impact tests and sled tests to evaluate how well a dummy replicates the behavior and response of a human being across various body regions. Rankings are calculated for both external and internal biofidelity. For this method, external biofidelity is a measure of how closely the dummy simulates PMHS external loadings onto the surrounding impact structures (as measured by pendulum and sled load plate force-time history responses), and internal biofidelity provides a measure of how closely the dummy's internal injury responses match those of PMHS (e.g. rib deflection) under similar conditions.[140] A lower ranking indicates a closer dummy response relative to that of the mean cadaver and thus better dummy biofidelity.

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[139] Rhule, H., Moorhouse K., Donnelly, B., & Stricklin, J. "Comparison of WorldSID and ES-2re Biofidelity Using an Updated Biofidelity Ranking System," The 21st International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 09-0563, 2009.

[140] Rankings for either internal or external biofidelity are based on the ratio of the cumulative variance of the dummy response relative to the mean cadaver response and the cumulative variance of the mean cadaver response relative to the mean plus one standard deviation. This ratio (e.g., ranking) expresses how well a dummy duplicates a cadaver response.

A dummy with a biofidelity ranking of less than 2.0 responds much like a human subject. The WorldSID-50M ATD has an overall external biofidelity ranking of 2.2 and internal biofidelity of 1.2 (without the abdomen). Biofidelity rankings of the WorldSID-50M ATD's individual body regions are given in Table 4.

Table 4. WorldSID-50M Side Impact Dummy Biofidelity– NHTSA BioRanks

Body Region	External Biofidelity	Internal Biofidelity
Head	-	0.3
Neck	-	0.8
Shoulder	1.0	0.9
Thorax	3.2	2.0
Abdomen	1.9	2.4
Pelvis	2.7	1.8
Overall (with Abdomen)	2.2	1.4
Overall (without Abdomen)	-	1.2

Source: Rhule, H., Moorhouse K., Donnelly, B., & Stricklin, J. "Comparison of WorldSID and ES-2re Biofidelity Using an Updated Biofidelity Ranking System," The 21st International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 09-0563, 2009.

In addition to the biofidelity ratings assessed by the ISO WorldSID Task Group and NHTSA, other evaluations have been conducted assessing WorldSID-50M ATD's biofidelity, particularly with the intent to evaluate rib deflection. One study, conducted under NHTSA contract at the Medical College of Wisconsin (MCW), found that the WorldSID-50M ATD was suitable for use in both pure lateral and oblique loading scenarios.[141] However, it was noted that the 2D IR-TRACCs still underreported deflection in oblique impacts; this was not the case for lateral impacts. The report also indicated that the lateral-most point of the rib may not be the

[141] Yoganandan, N., Humm, J.R., Pintar, F.A., & Brasel, K., "Region-specific deflection responses of WorldSID and ES2-re devices in pure lateral and oblique side impacts," Stapp Car Crash Journal, 55: pp. 351-378, 2011.

most adequate location for measuring thoracic and abdominal deflections in oblique loading and that evaluation of other deflection measurement systems may be warranted.

NHTSA then performed quasi-static testing to better understand how much the IR-TRACCs can underestimate deflection from oblique loading. A single WorldSID-50M rib was slowly compressed with a materials testing machine at 0 degrees (lateral), 20 degrees anterior-to-lateral, and 50 degrees anterior-to-lateral while photographs and videos were taken to document the IR-TRACC's motion. When loaded laterally, the IR-TRACC rotated somewhat, but as the point of load application became further from the point of IR-TRACC attachment, the IR-TRACC rotated to a greater degree, away from the application of loading. Even when the y-direction deflection was calculated using the rotation of the IR-TRACC and the compression of the telescoping IR-TRACC rod, in the extreme case of the 50-degree severely-oblique load, the IR-TRACC did not capture the full, maximum deflection of the rib. A similar response occurs in the SID-IIs ATD's shoulder, thoracic and abdominal ribs, which include linear potentiometers mounted at the lateral-most point of the rib, which will not capture maximum deflection if the point of loading is far from the potentiometer mount location.

Although these concerns have been raised, NHTSA is aware of research that shows that oblique crashes do not necessarily result in oblique loading to the dummy's chest. Though seemingly counterintuitive, Transport Canada and the Australian Government Department of Infrastructure and Transport has found that in oblique vehicle-to-pole crash conditions, such as

those used in FMVSS No. 214, the WorldSID-50M ATD actually experiences predominantly lateral peak rib deflection responses.[142]

Nonetheless, the use of an improved deflection measurement system may be valuable to pursue.[143] Thus, NHTSA intends to conduct further research to evaluate the use of RibEye™ optical sensors in the WorldSID-50M ATD's thorax and abdomen as an alternative to the 2D IR-TRACCs already provided. The RibEye™ system can measure the deflection of the inner ribs in the X, Y, and Z directions at three locations on each rib. This may serve to better monitor oblique deformation of the ribs.

iv. Repeatability and Reproducibility

The WorldSID-50M ATD's body regions demonstrated good repeatability and reproducibility when production versions of the dummy were subjected to certification tests performed per ISO 15830-2.[144] Repeatability is assessed by performing repeat tests on the same dummy, and reproducibility is determined by performing repeat tests on different dummies. Generally, a minimum of three trials were conducted per test. Repeatability was assessed based on the percent coefficient of variation (CV), which is defined as the standard deviation of the samples divided by the sample mean, expressed as a percentage. Responses having a CV of less than 5 percent are generally considered as having an excellent level of repeatability, those with a CV of 5-8 percent are considered good, those with a CV of 8-10 percent are considered

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[142] Belcher, T., Terrell, M. & Tylko, S., "An Assessment of WorldSID 50th Percentile Male Injury Responses to Oblique and Perpendicular Pole Side Impacts," The 22nd International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 11-0133, 2011.

[143] NHTSA research tests conducted with WorldSID dummies outfitted with chest bands showed cases of oblique loading for both front and rear seating locations in testing carried out using the Side NCAP MDB protocol.

[144] Scherer, R., Bortenschlager, K., Akiyama, A., Tylko, S., Hartleib, M., & Harigae, T., "WorldSID Production Dummy Biomechanical Responses," The 21st International Technical Conference for the Enhanced Safety of Vehicles Conference, Paper No. 09-0505, 2009.

acceptable, and those having a CV of more than 10 percent are generally considered as having an unacceptable or poor level of repeatability. The resulting CV for the dummy's various body parts was below 5 percent in many cases and below 10 percent in all measured cases, with the exception of lower spine T12 lateral acceleration when the dummy's thorax was assessed without the arm.[145] Values were generally in line with expectations – a CV for injury assessment of less than or equal to 7 percent.

v. Seating procedure

Although the impact protocols for the side MDB and pole tests will remain largely unchanged, slight modifications to the test procedures will have to be made to accommodate the new test dummy. It will be necessary to adjust the test weight calculation to accommodate the weight of the WorldSID-50M ATD as opposed to the current ES-2re or SID-IIs ATDs. The agency will need to make other minor changes with respect to data collection and reporting. Because of the WorldSID-50M ATD's anthropometrical differences compared to the ES-2re and SID-IIs ATDs, alterations to the seating procedure must also be made.

Several seating procedures for the WorldSID-50M ATD have been developed: the WorldSID working group version 5.4 (WSG 5.4) and the ISO/TS22/SC10/WG1's version (ISO/DIS 17949:2012, or GTR version). ISO/TS22/SC10/WG1 is a group established to develop car collision test procedures. The NHTSA WorldSID-50M ATD draft seating procedure (NWS50) that the agency has developed, found in the docket for this RFC notice, is based on the existing FMVSS No. 214 procedure for the ES-2re and the WSG 5.4 seating procedures.[146] In the NWS50 procedure, the seat position is 20 mm (0.79 in) rearward of mid-track position, as is

[145] For this test, the CV was 10.7%.
[146] WSG 5.4 Seating Procedure, placed in the docket of this RFC notice.

prescribed in WSG 5.4. Since the WorldSID-50M ATD's legs are longer than those of the ES-2re ATD, the adjusted seat track position at 20 mm (0.79 in) rearward of mid-track allows the legs to be placed in a more natural position. The final target for the H-point is modified to account for the rearward change in seat placement along the seat track by adding 20 mm (0.79 in) to the target H-point.[147]

The NWS50 procedure determines the mid angle of the seat pan at the beginning of seat positioning and keeps the seat pan at the lowest position while maintaining the mid-angle of the seat pan. This is in contrast to WSG 5.4 and GTR versions, which allow the seat pan angle to change if the seat pan can move to a lower position. The GTR, WSG 5.4, and NWS50 procedures are generally the same with respect to dummy positioning, with the exception of differences in tolerance values for leveling the head and the thorax and pelvis tilt sensors.[148] [149] [150]

vi. Fleet Testing

The agency has some experience with the WorldSID-50M ATD in a research capacity. NHTSA has evaluated the WorldSID-50M dummy in FMVSS No. 214 crash test protocols. After the 2007 Final Rule was released, an initial series of side MDB and pole tests was successfully conducted on the MY 2005 fleet. The evaluation examined the overall performance of the WorldSID-50M ATD. The anthropometry and testing results were discussed in a 2009 International Technical Conference for the Enhanced Safety of Vehicles paper and at the 2008

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[147] Louden, A., "WorldSID 50th Male Seating Evaluation and Fleet Testing," Society of Automotive Engineers Government/Industry Meeting, January 2012.
[148] NHTSA WS50th Seating Procedure, placed in the docket of this RFC notice.
[149] WSG 5.4 Seating Procedure, placed in the docket of this RFC notice.
[150] ECE/TRANS/180/Add.14

and 2009 SAE Government Industry Meetings.[151] [152] [153] A second fleet evaluation consisting of MDB and pole tests was conducted with MY 2010-2012 vehicles, in part to evaluate the seating procedure. This testing proved the feasibility of the NWS50 procedure. More detailed results of this testing were presented at the 2014 SAE Government Industry Meeting,[154] and the NHTSA database test numbers associated with this evaluation can be found in Appendix V.

vii. Durability

The WorldSID-50M ATD was designed with durability specifications in mind. ISO/TC22/SC12/WG5's requirements were that the dummy must remain functional for at least ten tests in which the dummy was subjected to loads up to 150 percent of IARVs established at the time.[155] In the dummy's development phase, the WorldSID-50M ATD's shoulder rib was found to permanently deform and IR-TRACC damage occurred as a result of excessive stroking (e.g., bottoming out) during the 8.9 m/s rigid wall sled test and the 2 m full-body drop test. Although these tests are considered quite severe, a rib doubler was added to the outer shoulder rib to strengthen it.[156] This change resulted in improved durability, as further testing undertaken by the ISO/TC22/SC12/WG5 showed no permanent deformation of the shoulder rib or IR-

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[151] Louden, A., "Dynamic Side Impact Testing with the 50th Percentile Male WorldSID Compared to the ES-2re," The 21st International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 09-0296, 2009; "Status of WorldSID 50th Percentile Male Side Impact Dummy," European Enhanced Vehicle-Safety Committee Working Group, 12 March 2009.
[152] Louden, A., "Side Impact Crash Testing with the 50th Percentile Male WorldSID," Society of Automotive Engineers Government/Industry Meeting, May 2008.
[153] Louden, A., "50th Male WorldSID Test Results in FMVSS 214 Test Conditions & ES-2re Comparisons," Society of Automotive Engineers Government/Industry Meeting, February 2009.
[154] Louden, A. and Weston, D., "WorldSID Status: 50th Male and 5th Female," Society of Automotive Engineers, Government/Industry Meeting, January 2014.
[155] ISO WorldSID Task Group, "Durability Requirements and Performance," [www.worldsid.org/Documentation/TG%20N394%20WorldSID%20Durability%20Requirements%20and%20Performance%2020050331.pdf]. Accessed 25 Sep 2015.
[156] ISO WorldSID Task Group, "Durability Requirements and Performance," [www.worldsid.org/Documentation/TG%20N394%20WorldSID%20Durability%20Requirements%20and%20Performance%2020050331.pdf]. Accessed 25 Sep 2015.

TRACC damage.[157] Furthermore, during full-scale side pole and barrier tests conducted with the WorldSID-50M ATD in the driver and/or rear passenger struck side position, no damage was observed for the head, neck, thorax, pelvis, or legs during visual inspections even though some injury readings were recorded as being up to three times the IARVs or had achieved the maximum measurement range.[158]

NHTSA's testing confirmed the ISO's durability findings. NHTSA's first round of side pole and MDB fleet testing with the WorldSID-50M ATD resulted in only minor damage to the dummies used during the test series. In one test, the dummy's shoulder IR-TRACC was observed to be damaged at both ends post-test. It was also discovered that the WorldSID-50M ATD's rib damping material de-bonded from the metal ribs over the course of the test series. This finding led to a change in the rib damping material.[159] It is worth noting that the damage to the shoulder IR-TRACCs only occurred during oblique pole tests, and the vehicles tested were not certified to the oblique pole side impact standards implemented in 2007.

During the agency's second round of fleet testing, part of the dummy's shoulder IR-TRACC was damaged in 2 of the 12 vehicles tested during pole testing, but this was the only notable damage.[160] None of the dummy's shoulder IR-TRACCs were damaged during side MDB testing.[161] Future vehicles should show not only reduced intrusion because of improvements made to strengthen vehicles' side structure, but they should also have greater side air bag

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[157] Ibid.
[158] Ibid.
[159] Louden, A., "Dynamic Side Impact Testing with the 50th Percentile Male WorldSID Compared to the ES-2re," The 21st International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 09-0296, 2009; "Status of WorldSID 50th Percentile Male Side Impact Dummy," European Enhanced Vehicle-Safety Committee Working Group, 12 March 2009.
[160] Louden, A., "WorldSID 50th Male Seating Evaluation and Fleet Testing," Society of Automotive Engineers Government/Industry Meeting, January 2012.
[161] Louden, A. & Weston, D., "WorldSID Status: 50th Male and 5th Female," Society of Automotive Engineers, Government/Industry Meeting, January 2014.

coverage to accommodate the range of occupants subjected to FMVSS No. 214 testing, which should serve to distribute the loads imparted to the test dummies. Side air bags in general, particularly chest and pelvis air bags, are now seen more often in larger vehicles.[162] With the incorporation of such changes, it is expected that a reduction in shoulder deflection would be seen in future testing with FMVSS No. 214-compliant vehicles.

viii. Instrumentation

Instrumentation for the WorldSID-50M ATD was designed to be easy to use and to comply with recognized instrumentation standards such as SAE J211 - Instrumentation for Impact Test and ISO 6487 - Measurement Techniques in Impact Tests - Instrumentation. The dummy's instrumentation supports the assessment of injury risk for practically all known side impact injury criteria used in existing side impact protocols worldwide and also supports the evaluation and optimization of vehicle components and restraint systems.[163]

The WorldSID-50M ATD can be instrumented with upper and lower neck load cells; 2D IR-TRACCs or RibEye™ in the shoulder rib, three thoracic ribs, and two abdomen ribs to measure displacement; a shoulder load cell; a pubic load cell; iliac and sacrum load cell; and accelerometers at numerous locations, including the head, upper and lower spine, ribs, and pelvis, to measure the "g" levels that are applied to the dummy during a side impact crash. Accelerometers placed at the head center of gravity measure linear and rotational accelerations, while angular rate sensors measure angular velocity of the head. With respect to the dummy's upper limbs, two arm configurations are available – half arms, which are standard, and full arms,

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[162] Park, B., Rockwell, T., Collins, L., Smith, C., & Aram, M., "The Enhanced U.S. NCAP: Five Years Later," The 24th International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 15-0314, 2015.
[163] ISO WorldSID Task Group, "Instrumentation," [www.worldsid.org/Documentation/TG%20N397%20Instrumentation%2020050401.pdf]. Accessed 28 Aug 2015.

which are optional. The dummy's upper and lower legs include load cells and rotational potentiometers, in addition to other sensors.

The WorldSID-50M ATD was also designed to have an optional in-dummy data acquisition system (DAS), which is wholly contained within the dummy and includes integrated wiring. This DAS, which has the ability to collect up to 224 data channels, eliminates the need for a single, large umbilical cable.[164] Current dummies require the use of an umbilical cable that runs from the dummy's spine to a DAS located elsewhere – either on or off the vehicle. These cables can add weight to the test vehicle. With the large amount of data channels possible for the WorldSID-50M ATD, an umbilical cable is not practical.

ix. Injury Criteria and Risk Curves

The construction of injury risk curves for the WorldSID-50M ATD was initiated in 2004 by the ISO Technical Committee 22, Sub-committee 12, Working Group 6 (ISO/TC22/SC12/WG6). Additional support for this project came from the Dummy Task Force of the Association des Constructeurs Europeens d'Automobiles (ACEA-TFD) in 2008. The ACEA-TFD aimed to promote consensus among biomechanical experts as to the injury risk curves that should be used. Subsequently, a group of biomechanical experts worked to develop injury risk curves for the WorldSID-50M ATD shoulder, thorax, abdomen, and pelvis.[165] These curves, which were released and discussed at the May 2009 meeting of ISO/TC22/SC12/WG6, were developed using the following process: (1) an extensive review of all available PMHS side impact test datasets (impactor tests and sled tests) worldwide was conducted, and those test

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[164] ISO WorldSID Task Group, "Background," [www.worldsid.org/Documentation/Background%2020051116.pdf]. Accessed 25 Sep 2015.
[165] Petitjean, A., Trosseille, X., Petit, P., Irwin, A., Hassan, J., & Praxl, N., "Injury Risk Curves for the WorldSID 50th Percentile Male Dummy," Stapp Car Crash Journal, 53: 443-476, 2009.

configurations that could be reproduced using the WorldSID-50M ATD were selected, (2) WorldSID-50M ATD responses from similar test configurations were obtained and scaled to simulate the same test severities the PMHS were exposed to by accounting for anthropometry differences between the PMHS and 50th percentile dummy, and (3) the scaled WorldSID-50M ATD data was paired with PMHS injuries for each body region and test condition to construct injury risk curves based on commonly used statistical methods. Although injury risk curves are historically constructed for AIS 3+ injuries, a well-distributed sample of injured and non-injured PMHS at this AIS level was not available for some body regions. In such instances, risk curves were developed for other AIS levels for which injury results were better balanced.[166] In most cases, the AIS levels evaluated were reduced. This should have the effect of addressing a larger amount of injuries in the real world.

When injury risk curves for the WorldSID-50M ATD were proposed by Petitjean et al. in 2009, there was no consensus on what injury criteria should be adopted or which statistical method – certainty, Mertz-Weber, consistent threshold estimate (CTE), logistic regression, or survival analysis with Weibull distribution – should be used to construct the injury risk curves from the test data. Ultimately, however, in 2011, after using statistical simulations to compare the performance of the different statistical methods, Petitjean et al. recommended that the Weibull survival method be used over the other statistical methods to construct injury risk curves for the WorldSID-50M ATD.[167] Around the same time, ISO/TC22/SC12/WG6 reached consensus on a set of guidelines that was to be used to not only build injury risk curves, but also to recommend the risk curve that is considered to be the most relevant to the sample studied. In

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[166] Ibid.
[167] NHTSA has historically used logistic regression to develop injury risk curves.

2012, Petitjean et al. applied these guidelines to the WorldSID-50M ATD results published in 2009 in order to provide a final set of injury risk curves for the WorldSID-50M ATD. These curves, which were specified for lateral shoulder force, thoracic rib deflection, abdomen rib deflection, and pubic force, were ultimately recommended by ISO/TC22/SC12/WG6.

The recommended risk curves for the WorldSID-50M ATD, as published by Petitjean et al. in 2012, were adjusted for both 45-year-olds and 67-year-olds.[168] The agency will decide on an appropriate age at which to scale risk curves for the WorldSID-50M ATD once final, adjusted population estimate data has been calculated and examined. The injury criteria and associated risk curves NCAP intends to use for the WorldSID-50M ATD are described below and detailed in Appendix IV of this document. The agency intends to adopt injury criteria to address head, shoulder, thorax, abdominal, and pelvis risk. Injury criteria for most of these body regions (head, thorax, abdomen, and pelvis) are currently included for the ES-2re dummy in FMVSS No. 214 and side NCAP. The injury criteria mentioned below are generally consistent with those recommended by ISO/TC22/SC12/WG6 and those currently under evaluation by the Working Party on Passive Safety (GRSP) for inclusion in the pole side impact GTR. With few exceptions, they are also used currently by Euro NCAP for rating vehicles.

The agency is seeking comment on the risk curves included herein, as well as all aspects of the following:

HEAD - NHTSA's preliminary analysis of real-world vehicle-to-vehicle and vehicle-to-pole side impact crashes showed that approximately one third (34%) of all AIS 3+ injuries for front seat, medium-stature occupants were to the head. The data reviewed showed that, of the AIS 3+ head injuries reported, 91 percent were brain injuries in vehicle-to-vehicle crashes, and 82

[168] Petitjean, 2012.

percent were brain injuries in vehicle-to-pole crashes.[169] As mentioned previously, HIC (either 15 milliseconds (ms) or 36 ms in duration) is a measure of only translational head acceleration; it does not account for rotational motion of the head, which has been commonly seen in side impact crashes and which may induce brain injury. To account for this rotational motion, the agency is planning to adopt the brain injury criterion, BrIC, for the WorldSID-50M dummy. The WorldSID-50M ATD can be equipped to measure rotational accelerations and/or rotational velocities at the head center of gravity. If accelerations are used, they must be integrated to obtain the rotational velocity used to calculate BrIC; however, if rotational velocity is measured directly, no further processing is necessary. Therefore, the agency intends to use angular rate sensors to calculate BrIC. The AIS 3+ risk curve associated with BrIC for the WorldSID-50M is included in Appendix IV.

As BrIC is intended to complement HIC rather than replace it, the agency will continue to measure HIC_{36} readings in side NCAP MDB and pole tests with the WorldSID-50M dummy. The AIS3+ risk curve associated with HIC_{36} is found in Appendix IV.

SHOULDER - The agency also intends to evaluate injuries stemming from the crash forces imparted to the WorldSID-50M ATD's shoulder. The agency's analysis of real-world vehicle-to-vehicle and vehicle-to-pole crashes showed that 13 percent of all AIS 2+ injuries reported for medium-stature occupants in the front seat were shoulder injuries.[170] The WorldSID-50M ATD's shoulder shows excellent biofidelity; recall that the ISO rating for the WorldSID-50M ATD's shoulder is 10, and its NHTSA external and internal BioRank scores are 1.0 and 0.9, respectively. Shoulder design can substantially affect dummy response during side

[169] NHTSA's review of NASS-CDS cases; see Real-World Data section.
[170] Ibid.

pole and side air bag interactions, and biofidelity is extremely important in narrow object crashes where the margins between minor and serious or fatal injury are relatively small.[171]

NHTSA has chosen to evaluate shoulder injury risk for the WorldSID-50M ATD as a function of maximum shoulder force in the lateral direction (Y). The associated AIS 2+ risk curve, developed by Petitjean et al. (2012), can be found in Appendix IV.

The agency has some concern that assessing shoulder injury risk in NCAP may prohibit manufacturers from offering the best thorax protection, as it may be necessary for vehicle manufacturers to direct loading in severe side impact crashes towards body regions that are best able to withstand impact, such as the shoulder, in order to divert loads away from more vulnerable body regions, such as the thorax. In fact, it is for these reasons that the side pole GTR informal working group decided not to establish a threshold for shoulder force based on the AIS 2+ injury risk curves developed by ISO/TC22/SC12/WG6.[172] That said, the informal working group thought it was still important to prevent non-biofidelic (e.g., excessive) shoulder loading so that vehicle manufacturers could not use such excessive shoulder loading to reduce thorax loading artificially. Accordingly, the informal working group agreed upon a maximum peak lateral shoulder force of 3.0 kN (674.4 lb-force). The agency's fleet testing showed maximum shoulder forces ranging from 1.2 kN (269.8 lb-force) to 2.6 kN (584.5 lb-force) for oblique pole tests and 876 N (196.9 lb-force) to 2.3 kN (517.0 lb-force) in the side impact MDB tests. The agency is requesting comments on the merits of using a performance criterion limit (e.g., IARV) instead of the AIS 2+ risk curve for shoulder force in NCAP ratings.

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[171] ECE/TRANS/180/Add.14
[172] Ibid.

Petitjean et al. did not recommend an injury risk curve for shoulder deflection for the WorldSID-50M ATD because, during development of the risk curves, shoulder deflection data was only available for impactor tests, whereas shoulder force data was available for both impactor and sled tests. Since a wider range of test configurations could be used to build an injury risk curve for shoulder force compared to shoulder deflection, only a curve for maximum shoulder force was recommended.[173] The decision to recommend one injury risk per body region, injury type, and injury severity was in keeping with the guidelines agreed to by the ISO/TC22/SC12/WG6 experts.

The agency notes that it does not subscribe to these guidelines universally. For example, the Hybrid III ATD chest deflection and acceleration are both used as separate indicators of injury in FMVSSs. That said, the agency is requesting comments on the merits of also adopting a risk curve for AIS 2+ shoulder injury that is a function of shoulder deflection, as this risk curve has also been developed by ISO/TC22/SC12/WG6.[174]

CHEST - The NASS-CDS data examined showed that, in addition to the head, the chest is one of the most common seriously injured body regions in side crashes. Thirty-four percent of all AIS 3+ injuries to front seat, medium-stature occupants involved in vehicle-to-vehicle and vehicle-to-pole crashes were thoracic injuries.[175] As such, NHTSA intends to incorporate chest deflection injury criteria to measure thoracic injury for the WorldSID-50M ATD.

Petitjean et al., 2012 developed an injury risk function to relate maximum thoracic and abdominal rib deflection of the WorldSID-50M ATD, as measured by a 1D IR-TRACC, to AIS

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[173] Petitjean, A., Trosseille, X., Praxl, N., Hynd, D., Irwin, A., "Injury Risk Curves for the WorldSID 50th Male Dummy," Stapp Car Crash Journal, 56: 323-347, 2012.
[174] ISO/TR 12350:2002(E).
[175] NHTSA's review of NASS-CDS cases; see Real-World Data section.

3+ thoracic skeletal (and abdominal skeletal) injury obtained from PMHS. This risk curve, presented in Appendix IV, is a function of both thoracic and abdominal rib deflection because the abdominal ribs of the WorldSID-50M dummy partially overlap the thorax ribs of a mid-size adult male.[176] Because of this, increased loading of the WorldSID-50M ATD's abdominal ribs would be expected to increase the risk of both AIS 3+ thorax and AIS 3+ abdominal injuries. Although chest deflection has been shown to be the best predictor of thoracic injuries in side impact crashes, the agency has some concerns, as mentioned previously, regarding the WorldSID-50M ATD's ability to accurately measure deflections under oblique loading conditions. It should be noted that Petitjean et al. concluded that, for impact directions from lateral to 15° forward of lateral, the injury risk curves that would be constructed for thoracic deflection using the Y-component of the deflection measured by a 2D IR-TRACC would be close to those developed for deflection measured by a 1D IR-TRACC.[177] The authors also concluded that, for air bag tests, the deflection measured by the 1D IR-TRACC can be used as criteria for an impact direction between pure lateral and 30° forward of lateral. However, Hynd et al., 2004 concluded that for rearward oblique loading, a 1D IR-TRACC would underestimate rib deflection, and therefore, a 2D IR-TRACC or RibEye™ may more accurately reflect actual deflection under such loading conditions.[178] Research with the WorldSID-50M ATD using the optical sensing system, RibEye™, is ongoing.

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[176] As indicated in Petitjean 2009, the maximum of the three thorax rib and two abdomen rib deflections was used to develop the thorax injury risk curves. This was done to be consistent with AIS 2005, which specifies that all rib fractures are used to code thoracic skeletal injuries.
[177] Petitjean, A., Trosseille, X., Praxl, N., Hynd, D., & Irwin, A., "Injury Risk Curves for the WorldSID 50th Male Dummy," Stapp Car Crash Journal, 56: 323-347, 2012.
[178] Hynd, D., Carroll, J., Been, B., & Payne, A., "Evaluation of the Shoulder, Thorax, and Abdomen of the WorldSID Pre-Production Side Impact Dummy," Research Laboratory Published Project Report. 2004. PPR 029.

Other thoracic injury criteria adopted by ISO/TC22/SC12/WG6 are maximum thoracic rib and abdomen rib viscous criteria, or VC, which are designed to address both soft tissue and skeletal injuries. The agency has not found VC to be repeatable and reproducible in the agency's research;[179] however, the agency realizes that many other organizations, including regulatory authorities, have been using VC for the EuroSID 1 and the ES-2 dummies in side impact MDB testing, including ECE Regulation No. 95, for many years. As ISO/TC22/SC12/WG6 has not yet been able to construct an AIS 3+ thoracic VC injury risk curve with an acceptable quality index for the WorldSID-50M percentile male dummy, the agency will not incorporate a peak thoracic VC into side NCAP for the next upgrade.

ABDOMEN - A smaller, yet still notable, portion of real-world injuries in side impact crashes are abdominal injuries. The agency's review of the NASS-CDS database showed that 15% of all AIS 2+ injuries for front seat, medium-stature occupants in vehicle-to-vehicle and vehicle-to-pole side impact crashes were abdominal injuries.[180] The biofidelity rating for the WorldSID-50M ATD's abdomen is greatly improved; the ISO rating for the WorldSID-50M's abdomen is a 9.3 and external and internal BioRank scores are 1.9 and 2.4, respectively. Accordingly, as part of the upgrade to NCAP, the agency intends to include abdominal rib deflection injury criterion for the WorldSID-50M ATD.

Whereas the thoracic rib deflection criterion discussed in the previous section is designed to assess both thoracic and abdominal skeletal injuries, the maximum abdomen rib deflection injury criterion is designed to gauge abdominal soft tissue injuries. Risk curves showing AIS 2+

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[179] See 69 FR 28002. Docket No. NHTSA-2004-17694. Available at https://federalregister.gov/a/04-10931.
[180] NHTSA's review of NASS-CDS cases; see Real-World Data section.

abdomen soft tissue injury for the WorldSID-50M ATD as a function of maximum abdomen rib deflection measured by a 1D IR-TRACC can be found in Appendix IV.

This abdominal rib deflection injury criterion, which was developed and recommended by Petitjean et al. and adopted by ISO/TC22/SC12/WG6, was selected over the maximum abdomen rib VC to assess the risk of AIS 2+ abdominal soft tissue injuries because the quality index associated with the abdomen rib deflection was better than the abdomen rib VC.[181] In keeping with the ISO/TC22/SC12/WG6 guidelines to recommend one injury risk per body region, injury type, and injury severity, and in light of the agency's past experience with VC, mentioned above, the agency will not adopt an abdominal injury criterion based on maximum abdominal VC.

The agency is requesting comment on whether it is appropriate to also adopt a resultant lower spine injury criterion in hopes of capturing severe lower thorax and abdomen loading that is undetected by unidirectional deflection measurements, such as excessive loadings behind the dummy, which may cause excessive forward rotations of the ribs.[182] Resultant spinal accelerations have been shown to provide a good measure of the overall load on the thorax and, because they are being derived from tri-axial accelerometers (x, y, and z direction), are less sensitive to the direction of impact.[183] Adopting an additional criterion for lower spine acceleration would be in line with what the informal working group has decided for the side pole GTR. The informal working group agreed that the lower spine acceleration should not exceed 75 g, except for intervals whose cumulative duration is not more than 3 ms.

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[181] Petitjean, A., Trosseille, X., Praxl, N., Hynd, D., Irwin, A., "Injury Risk Curves for the WorldSID 50th Male Dummy," Stapp Car Crash Journal, 56: 323-347, 2012.
[182] ECE/TRANS/180/Add.14
[183] Kuppa, S. "Injury Criteria for Side Impact Dummies," National Highway Traffic Safety Administration, January 2006.

PELVIS - The agency's preliminary review of real-world data showed that pelvis injuries represent 13% of all AIS 2+ injuries for front seat, mid-size occupants involved in vehicle-to-vehicle crashes, and 20% of all AIS 2+ injuries for these occupants in fixed narrow object side impact crashes.[184] To evaluate pelvis injuries in side NCAP testing using the WorldSID-50M ATD, the agency intends to adopt pubic force as an additional injury criterion.

As mentioned earlier, the WorldSID-50M ATD is capable of measuring lateral pelvis acceleration and posterior sacro-iliac loads in addition to anterior pubic symphysis loads. At this time, however, the agency will only incorporate pubic symphysis injury criteria for the pelvis. The agency believes that adding a criterion to evaluate pubic symphysis loads instead of lateral pelvis acceleration is appropriate because most of the pelvis injuries observed in the PMHS samples reviewed by Petitjean et al. were ilioischial rami and pubic symphysis injuries.[185] Furthermore, pubic force is generally considered to be a more acceptable biomechanical measure than lateral pelvis acceleration.[186] The agency will also not adopt a criterion for sacro-iliac loads because a risk curve for the sacro-iliac has not yet been developed for the WorldSID-50M ATD. However, because the agency is aware that field evidence suggests that posterior pelvic injury may not be detected by the pubic symphysis load cell, the agency is requesting comment on how the pubic symphysis and sacro-iliac loads interrelate, and whether it is possible and necessary to establish injury criteria for both pelvic regions.

Human tolerance to pelvic loading has been established and related to the WorldSID-50M ATD, resulting in an injury risk curve, included in Appendix IV, to relate the measured

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[184] NHTSA's review of NASS-CDS cases; see Real-World Data section.
[185] Petitjean, A., Trosseille, X., Praxl, N., Hynd, D., & Irwin, A., "Injury Risk Curves for the WorldSID 50th Male Dummy," Stapp Car Crash Journal, 56: 323-347, 2012.
[186] Ibid.

maximum pubic symphysis force to the risk of an AIS 2+ pelvis injury. As risk of pelvic injury is currently assessed in side NCAP and FMVSS No. 214 at the AIS 3+ level, the agency is requesting comments on the merits of adopting the AIS 3+ risk curve for pubic symphysis force that was also recommended by Petitjean et al. instead.

b. SID-IIs ATD

i. Background

The SID-IIs dummy was developed by the Occupant Safety Research Partnership (OSRP), a research group under the umbrella of the U.S. Council for Automotive Research (USCAR), in 1993. At the time, there was a need for an ATD that would better evaluate a smaller occupant's biomechanical response to side impact countermeasures such as air bags. The SID-IIs dummy represents not only a 5th percentile female but all smaller occupants in general, including a preteen child. In the 2007 FMVSS No. 214 Final Rule, it was estimated that 34 percent of all serious and fatal injuries to near-side occupants in side impact crashes occurred to occupants 163 cm (5 ft 4 in) or less - occupants best represented by the SID-IIs ATD.[187] In narrow object side impacts in particular, drivers of smaller-stature comprised approximately 28 percent of seriously or fatally injured occupants. Of these smaller occupants, head, abdominal, and pelvic injuries represented a higher proportion of serious injury than larger occupants. By including a smaller-stature occupant in side impact crash regulations in 2007, the agency aimed to require comprehensive side impact occupant protection strategies for drivers of various sizes. Other organizations, such as the IIHS, also use the SID-IIs ATD in side crash tests.

[187] See 72 FR 51909. Docket No. NHTSA-29134. https://federalregister.gov/a/07-4360.

Preliminary data from NHTSA shows that a similar percentage of small-stature occupants are being injured in side impact crashes.[188] Thus, the agency believes it is appropriate to continue assessing risk of injury for this occupant size. Some of the SID-IIs ATD's risk curves will remain unchanged; these include HIC_{36} and combined pelvic force. Additional injury assessments to be included in the side impact rating are: BrIC, thoracic and abdominal rib deflection, and lower spine resultant acceleration criteria.

ii. Continuation of Current Injury Criteria

Currently, the SID-IIs dummy is placed in both the driver's seat of the side oblique pole NCAP test as well as the rear passenger seat of the side MDB NCAP test. Head acceleration and combined pelvic force are measured and risk curves are applied to estimate the probability of injury to each body region for rating purposes. The agency has not received any indication that these criteria should be amended or omitted from future iterations of NCAP; therefore, the agency intends to continue applying the risk curves to the dummy's head and pelvis.[189]

iii. New Injury Criteria Being Implemented

Thoracic and abdominal rib deflections for the SID-IIs ATD are currently collected, but they are only being monitored at this time. This RFC notice announces the agency's intent to add thoracic and abdominal injury criterion to the next version of its consumer information program for the SID-IIs ATD. It also announces the agency's intent to incorporate lower spine resultant acceleration performance limits and BrIC for the SID-IIs ATD into the side NCAP ratings in an integrated manner.

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[188] NHTSA's review of NASS-CDS cases; see Real-World Data section. NHTSA data shows that 36% of AIS 3+ injuries in side impacts occurred to occupants 5 ft 4 in or less (small-stature). Sixteen percent of occupants in narrow object side impact crashes which received MAIS 3+ injuries were of small-stature.
[189] Details of these risk curves are provided in Appendix IV.

BrIC - According to NHTSA's analysis, for small-stature occupants seated in the outboard rear row in a side-impact crash, just 6 percent of AIS 3+ injuries were head injuries. However, of those head injuries, all were to the brain.[190] Although this is a relatively small proportion of injury and other body regions are injured more frequently at this severity, traumatic brain injury can have very serious consequences. Furthermore, the SID-IIs dummies can be instrumented with rotational sensors. As with other dummies, HIC_{36} only accounts for translational head acceleration. As such, the agency intends to adopt BrIC in addition to HIC_{36} for the SID-IIs ATD in NCAP. The AIS 3+ risk curve associated with BrIC for the SID-IIs 5th percentile dummy is included in Appendix IV.

Thoracic and Abdominal Rib Deflections - The agency did not propose or adopt limits or risk curves for the SID-IIs ATD ribs in the 2007 FMVSS No. 214 upgrade. NHTSA was interested in solely monitoring rib deflections and was not prepared to limit rib deflections in FMVSS No. 214 at that time, though it did acknowledge that limits were possible for the future.[191] Since the SID-IIs Build D ATD's inclusion into the agency's consumer crash testing program in MY 2011, NHTSA has monitored the rib deflections gathered in side MDB and side pole crash testing.

Commenters to the agency's 2013 RFC asserted that deflection is a better predictor of torso injury than acceleration.[192] In terms of real-world data, chest injuries make up 26 percent of AIS 3+ injuries to small-stature, rear seat occupants in vehicle-to-vehicle crashes, and abdominal

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[190] NHTSA's review of NASS-CDS cases; see Real-World Data section.
[191] See 72 FR 51925. Docket No. NHTSA-29134. Available at https://federalregister.gov/a/07-4360.
[192] "New Car Assessment Program," Docket No. NHTSA-2012-0180.

injuries account for 22 percent of AIS 3+ injuries.[193] Thus, the agency feels that it is appropriate to incorporate thoracic and abdominal injuries for small occupants into this NCAP upgrade.

Research from the OSRP noted that the SID-IIs dummy's linear potentiometers may not capture the full extent of chest deflection in oblique loading conditions.[194] However, given the safety need, NHTSA believes that inclusion of thoracic and abdominal injury evaluations in NCAP should not be further delayed. The use of the SID-IIs ATD linear potentiometers will not over predict injury risk.

The AIS 3+ and AIS 4+ risk curves for SID-IIs ATD thoracic and abdominal deflection, respectively, can be found in Appendix IV. The risk curves the agency intends to use have been scaled for a 56-year-old female and have been adjusted to take into account lowered bone density. At the time of the curve's development, the average age of an AIS 3+ injured occupant 5 ft 4 in or less in height in side crashes was found to be 56 years.[195] Furthermore, this approach should ensure that safety information for the vulnerable population of occupants which the SID-IIs ATD is meant to represent is provided to the public. The agency seeks comment on whether this is an acceptable approach or whether the risk curves should be adjusted to a different age.

Lower Spine Acceleration - Lower spine (T12) resultant acceleration is also collected; currently, if it exceeds the criterion established in FMVSS No. 214 (82 g), the vehicle receives a Safety Concern designation for the applicable side impact test mode. Lower spine resultant acceleration was not included in the agency's upgraded consumer information program in MY 2011 because no validated risk curve was available at the time and there was no method by

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[193] NHTSA's review of NASS-CDS cases; see Real-World Data section.
[194] Jensen, J., Berliner, J., Bunn, B., Pietsch, H., Handman, D., Salloum, M., Charlebois, D., & Tylko, S., "Evaluation of an Alternative Thorax Deflection Device in the SID-IIs ATD," The 21st International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 09-0437, 2009.
[195] Kuppa, S. "Injury Criteria for Side Impact Dummies," National Highway Traffic Safety Administration, January 2006.

which to include performance limits in the star rating.[196] The agency still does not have a risk curve which it believes is appropriate for the SID-IIs ATD's lower spine resultant acceleration, but NHTSA intends to incorporate a performance criterion limit (IARV) for resultant lower spine acceleration for the SID-IIs ATD in this NCAP upgrade. Although deflection is thought to be the best indicator of injury, lower spine acceleration indicates the magnitude of overall loading to the thorax and may be able to detect injurious loads which the rib potentiometers may not. The agency seeks comment on an appropriate performance criterion limit for the SID-IIs ATD lower spine resultant acceleration.

c. WorldSID 5th Percentile Female ATD (WorldSID-5F)

i. Background and Current Status

After the development of the WorldSID-50M ATD in 2004, work on the WorldSID-5F ATD was initiated by the FP6 Advanced Protection System (or APROSYS) Integrated Project, a European Commission (EC) 6th Framework collaboration research project.[197] [198] APROSYS is a consortium of experts consisting of vehicle manufacturers, parts suppliers, universities/research institutions, and representative organizations from EU member states.[199] It was anticipated that a smaller version of the dummy could be nearly as, if not equally, biofidelic as the larger version. The hope was to create a family of dummies which provide consistent direction to manufacturers

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[196] See 73 FR 40029. Docket No. NHTSA-2006-26555. Available at https://federalregister.gov/a/E8-15620.
[197] Humanetics ATD, "WorldSID 5th Small Female Dummy,' [www.humaneticsatd.com/crash-test-dummies/side-impact/worldsid-5th]. Accessed 25 Sep 2015.
[198] Been, B., Meijer, R., Bermond, F., Bortenschlager, K., Hynd, D., Martinez, L., & Ferichola, G., "WorldSID Small Female Side Impact Dummy Specifications and Prototype Evaluation," The 20th International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 07-0311, 2007.
[199] Versmissen, T., "APROSYS Car to pole side impact activities," GRSP PSI meeting, March 2011.

to design crashworthiness countermeasures for occupants of various sizes.[200] The first prototype was assembled in October 2005; Revision 1 (also called Build Level B) was developed in 2007-2008. The current build level is Build Level C.

As with the larger WorldSID ATD, the WorldSID-5F's anthropometrical requirements were determined from the 1983 UMTRI automotive posture and anthropometry study. The dummy's target mass is 45.8 kg (101 lb) +/- 1.2 kg (2.7 lb) when equipped with two half-arms. Similar to the WorldSID-50M ATD, the WorldSID-5F ATD is more reclined when seated in a vehicle seat.[201]

The WorldSID-5F ATD allows for 125 dynamic measurements to be evaluated, including those for the head, upper and lower neck, shoulder, thorax, abdomen, lumbar spine, pelvis, femur, and tibia. The dummy's ribs can be instrumented with 2D IR-TRACCs or with the RibEye™ optical measurement system, similar to the WorldSID-50M ATD.

Biofidelity performance parameters for this dummy originated from the WorldSID-50M ATD and were scaled for a 5th percentile female.[202] ISO/TR9790 biofidelity evaluation tests have not been performed for Build Level C, but testing carried out for the Build Level B dummy showed that the WorldSID-5F ATD is as biofidelic as the WorldSID-50M ATD.[203] Biofidelity ratings for the Build Level B dummy are shown below in Table 5. Humanetics believes that

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[200] Carroll, J., Goodacre, O., Hynd, D., & Petitjean, A., "Testing of the WorldSID-5F to Support Injury Risk Function Development and Assessment of Other Performance Issues," The 23rd International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 13-0193, 2013.
[201] Louden, A. & Weston, D., "WorldSID Status: 50th Male and 5th Female," Society of Automotive Engineers, Government/Industry Meeting, January 2014.
[202] Eggers, A., Schnottale, B., Been, B., Waagmeester, K., Hynd, D., Carroll, J., & Martinez, L., "Biofidelity of the WorldSID Small Female Revision 1 Dummy," The 21st International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 09-0420, 2009.
[203] Ibid.

because the changes made for the Build Level C dummy were relevant to handling and durability only, they will not affect the biofidelity or dynamic response of the dummy.[204]

Table 5. WorldSID-5F Side Impact Dummy Biofidelity– ISO Ratings

	Head	Neck	Shoulder	Thorax	Abdomen	Pelvis	Overall
WorldSID-5F B	10	6.5	7.4	6.9	8.5	6.5	7.6

Sources: Eggers, A., Schnottale, B., Been, B., Waagmeester, K., Hynd, D., Carroll, J., & Martinez, L., "Biofidelity of the WorldSID Small Female Revision 1 Dummy," The 21st International Technical Conference for the Enhanced Safety of Vehicles Conference, Paper No. 09-0420, 2009.; 71 FR 75347

ii. Testing, Issues, and Current Status

Testing conducted with the WorldSID-5F ATD shows that there are still issues to address concerning this dummy.

As mentioned, biofidelity testing was conducted by Eggers et al. in 2009 to determine whether the WorldSID-5F's dynamic response was appropriate for a 5th percentile female.[205] Six drop tests, 22 pendulum tests, and 27 sled tests were performed using a Build Level B dummy in this series. Some of the testing was not conducted: the 10 m/s abdominal pendulum test, for example, was not run because of a height restriction within the test facility. In these cases, a linear trend line was fitted to the lower-speed data and the higher-speed data was extrapolated from the trend. This analysis found that the chest may be too stiff, and the authors suggested that the use of the resultant rib deformation, which overestimates the deformation, could compensate for the stiffness.

[204] Humanetics ATD, "WorldSID 5th Small Female Dummy,' [www.humaneticsatd.com/crash-test-dummies/side-impact/worldsid-5th]. Accessed 17 Sep 2015.
[205] Eggers, A., Schnottale, B., Been, B., Waagmeester, K., Hynd, D., Carroll, J., and Martinez, L., "Biofidelity of the WorldSID Small Female Revision 1 Dummy," The 21st International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 09-0420, 2009.

In an effort to further evaluate the WorldSID-5F's biofidelity and develop appropriate risk curves, TRL subjected the Build Level B dummy to additional pendulum and sled testing.[206] In this group of tests, 26 sled tests and 51 pendulum tests were performed. Unlike the previous testing undertaken by Eggers et al., some higher-severity tests, such as the 8.7 m/s Wayne State University thoracic impactor test and the 10 m/s Wayne State University pelvic impactor test, were not completed as planned as TRL felt that the ATD reached its maximum sustainable impact shortly after 6 m/s. Thus, the projected results from a more severe test were again achieved by fitting a straight line to the peak deflection results and extrapolating; TRL noted that this is not ideal. This analysis found that most of the ATD's body regions (shoulder, thorax, abdomen, and pelvis) are rather stiff.

It also uncovered some additional dummy design issues regarding shoulder load cell contact with the neck bracket, iliac wing contact with the sacro-iliac load cell and lumbar load cell cable cover, and upper central iliac wing contact with the lumbar spine mounting plate. For the shoulder, this contact may restrict the deflection allowed to 40 mm, depending on the vertical displacement of the rib.[207] The contacts within the pelvis were causing loading in unintended areas within the dummy. Humanetics modified parts to evaluate whether the contacts would be eliminated; contacts at lower speeds did not occur, but testing at higher impact speeds still showed iliac contact with the surrounding structures.[208] Also, prior testing with the WorldSID-50M ATD showed that interference may occur between the pelvic flesh and the lower abdominal rib, depending on how the dummy is seated. Interaction between the two causes the abdominal

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[206] Carroll, J., Goodacre, O., Hynd, D., & Petitjean, A., "Testing of the WorldSID-5F to Support Injury Risk Function Development and Assessment of Other Performance Issues," The 23rd International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 13-0193, 2013.
[207] Ibid.
[208] Ibid.

response to be stiffer. TRL's testing showed that this problem also exists for the WorldSID-5F ATD, though to a lesser degree as TRL believed that it is unlikely to occur with normal use of the dummy.

NHTSA has successfully performed full-scale vehicle crash tests with the WorldSID-5F prototype. In these tests, a WorldSID-50M ATD was seated in the driver's seat and a WorldSID-5F ATD was seated in the left rear seat. The vehicle was then subjected to the agency's MDB test at the side NCAP speed. Through these rounds of testing, it was determined that the WorldSID-5F ATD is durable; nothing was damaged in the NHTSA side MDB testing. A list of NHTSA database test numbers for these tests can be found in Appendix V.

Additional dummy issues have been identified over the course of the WorldSID-5F's testing. Material changes must be made in the head and pelvis. These limitations will require redesigns of the applicable sections of the dummy. Furthermore, risk curves for this dummy must be developed. These concerns must be addressed before the WorldSID-5F can be included in the next NCAP upgrade.

C. Crashworthiness Pedestrian Protection

NHTSA intends to implement vehicle crashworthiness tests for pedestrian safety in the NCAP program. The agency believes that including pedestrian protection in the NCAP program would have a beneficial impact on pedestrian safety. As will be discussed in a later section, the crashworthiness pedestrian safety assessment will be part of the new rating system.

1. Real-World Pedestrian Data

Since 1975 when NHTSA began tracking fatalities, there have been approximately 4,000 pedestrian fatalities and 70,000 pedestrian injuries on U.S. roads annually. In 2012, there were

4,818 pedestrian fatalities, which accounted for approximately 14 percent of all motor vehicle-related fatalities.[209]

The majority of fatal pedestrian crashes involve light vehicles.[210] About one-third of pedestrians who are injured are struck by an SUV or pickup truck (see Appendix VII, Table VII-1), which corresponds closely to the make-up of SUVs and pickups in the U.S. vehicle fleet. However, SUVs and pickups account for closer to 40 percent of pedestrian fatalities, which suggests that injuries may be more severe when sustained in collisions with these vehicles. Results from a meta-analysis of 12 independent injury data studies showed that pedestrians are 2-3 times more likely to suffer a fatality when struck by an SUV or pickup truck than when struck by a passenger car.[211] Laboratory tests reflect this real-world data observation.[212] [213] [214] The higher risk of fatality associated with being struck by an SUV or pickup also applies to a vulnerable population – children. In a study conducted by Columbia University, school-age children (5 to 19 years old) struck by light trucks were found to be twice as likely to die as those struck by passenger cars.[215] The risk was even greater for the younger set (ages 5-9); their fatality risk is four times greater from SUVs and pickup trucks than from passenger cars.

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[209] Traffic Safety Facts, 2013, Pedestrians, DOT HS 812 124.
[210] Light vehicles (as referred to herein) include all vehicles with GVWR < 10,000 lbs, which generally includes all SUVs and pickup trucks.
[211] Desapriya, E. et al. (2010), "Do light truck vehicles (LTV) impose greater risk of pedestrian injury than passenger cars? A meta-analysis and systematic review." Traffic Injury Prevention, V11:48-56, 2010.
[212] Kerrigan, J., Arregui, C., & Crandall, J.C., "Pedestrian head impact dynamics: comparison of dummy and PMHS in small sedan and large SUV impacts," Paper No. 09-0127, The 21st International Technical Conference on the Enhanced Safety of Vehicles Conference, Stuttgart, Germany, June 15–18, 2009.
[213] Anderson, R. W. G. & Doecke, S. (2011), "An analysis of head impact severity in simulations of collisions between pedestrians and SUVs, work utility vehicles, and sedans," Traffic Injury Prevention, V12(4):388-397, 2011.
[214] Ivarrson, B. J., Henary, B. et al. (2005), "Significance of adult pedestrian torso injury," Annu Proc Assoc Adv Automot Med 49: 263-77.
[215] DiMaggio, C., Durkin, M., & Richardson, L. "The association of light trucks and vans with pediatric pedestrian fatality." Int J Injury Contr and Safety Prom 2006; 13(2):95-99.

In comparison to motor vehicle occupants, the distribution of pedestrian fatalities is greater for age groups that include children and people over 45 years old (see Appendix VII, Figure VII-1). The agency believes that a crashworthiness pedestrian safety program in NCAP is necessary to stimulate improvements in pedestrian crashworthiness in new light vehicles sold in the United States and ultimately reduce pedestrian fatalities and injuries from vehicle crashes in the United States. Europe and Japan have responded to the high proportion of pedestrian fatalities compared to all traffic fatalities by including pedestrian protection in their respective NCAPs and requiring pedestrian protection through regulation. These actions have likely contributed to a downward trend in pedestrian fatalities in Europe and Japan (see Appendix VII, Figure VII-2).

As opposed to Europe and Japan, fatalities in the United States have remained steady over the last 14 years (see Appendix VII, Figure VII-3). The agency believes that including pedestrian protection in the NCAP program would be a step toward realizing similar downward trends experienced in regions of the world that include pedestrians in their consumer information programs.

2. Current NCAP Activities in the U.S./World

NHTSA intends to implement vehicle crashworthiness tests for pedestrian safety. This plan follows the agency's April 2013 RFC notice in which it asked whether the agency should consider such testing in the NCAP program. Though opinion varied on its inclusion, a common thread among many commenters was a desire for worldwide harmonization of tests and protocols if a pedestrian testing or rating program was introduced. In consideration of this, the test

procedures and scoring scheme that the agency plans to use is essentially the same as those of Euro NCAP. [216]

The speeds at which Euro NCAP conducts its pedestrian protection tests are supported by the agency's data regarding speeds at which the greatest number of pedestrian impacts occurred. However, the agency plans to conduct its own tests independently from Euro NCAP.

3. Planned Upgrade

The agency intends to use the Euro NCAP test procedures rather than those of KNCAP or JNCAP because the European fleet make-up, including vehicle sizes and classes, is more similar to the U.S. fleet. Moreover, the societal benefits of the Euro NCAP pedestrian component are well documented. Recent retrospective studies indicate that ratings are yielding positive results in the European Union (E.U.) based on studies of their effect on real-world crashes and injuries. One such study was reported by the Swedish Transport Administration in 2014. A correlation between higher rating in Euro NCAP pedestrian protection scores and reduced head injuries and fatalities was observed among Swedish pedestrians struck between January 2003 and January 2014.[217] Similar observations were observed by BAST[218] for pedestrian collisions in Germany in the years 2009 to 2011.

The following is a list of Euro NCAP documents that NHTSA plans to use as a basis for its own test procedures:

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[216] NHTSA's plan as to how the pedestrian safety rating will factor into the overall vehicle rating is discussed later in this document, but that will not be identical to how Euro NCAP calculates their overall ratings.
[217] Standroth, J. et al. (2014), "Correlation between Euro NCAP pedestrian test results and injury severity in injury crashes with pedestrians and bicyclists in Sweden," Stapp Car Crash Journal, Vol. 58 (November 2014), pp. 213-231.
[218] Pastor, C., "Correlation between pedestrian injury severity in real-life crashes and Euro NCAP pedestrian test results," The 23rd International Technical Conference on the Enhanced Safety of Vehicles, Paper No. 13-0308, 2013.

(1) *Pedestrian Testing Protocol, Version 8.1, January 2015.* This describes the vehicle preparation, the test devices and their qualification requirements, and procedures to carry out the tests.

(2) *Pedestrian Testing Protocol, Version 5.3.1, November 2011.* If a vehicle manufacturer elects not to provide NHTSA with headform impact assessment data, the headform test protocol in V5.3.1 will be followed in lieu of V8.1.

(3) *Euro NCAP Pedestrian Headform Point Selection, V12.* The routine contained within this (Microsoft Excel) file is used to generate verification points to be tested by NHTSA.

(4) *Technical Bulletin TB 019, Headform to Bonnet Leading Edge Tests, Version 1.0, June 2014.* This document describes a procedure for child headform testing under the special case when test grid points lie forward of the hood and within the grille or hood leading edge area.

(5) *Film and Photo Protocol, Version 1.1, Chapter 8 – Pedestrian Subsystem Tests, November 2014*. This document describes camera set-up procedure only.

(6) *Technical Bulletin, TB 013, Pedestrian CAE Models & Codes, Version 1.4, June 2015.* This document lists various computer-aided engineering models that have been deemed acceptable for use by a vehicle manufacturer in demonstrating the operation and performance of an active hood.

(7) *Technical Bulletin, TB 008, Windscreen Replacement for Pedestrian Testing, Version 1.0, September 2009.* This document describes exceptions on bonding agents when windshields are replaced during the course of a vehicle test series.

(8) *Assessment Protocol – Pedestrian Protection, Part 1 –Pedestrian Impact Assessment, Version 8.1, June 2015.* Once all test data are collected, this protocol is used to determine the results.

NHTSA intends to publish and maintain its own set of procedures and assessment protocols. However, the agency intends for them to be fundamentally the same as those described above, though some revisions will be needed to align with the agency's current practices under NCAP. Among such revisions is defining how manufacturers will communicate with NHTSA on providing information needed to conduct tests. Also, revisions may be necessary to account for differences in vehicle fleet composition (i.e., test zone markup of large vehicles may differ slightly from Euro NCAP) or how the various test types are weighted to calculate the overall pedestrian protection score. NHTSA will consider whether to harmonize with any future revision put forth by Euro NCAP.

4. Test Procedures/Devices

The pedestrian safety assessment program the agency intends to implement is derived from multiple tests carried out on a stationary vehicle. The procedures are meant to simulate a pedestrian-to-vehicle impact scenario of either a 6-year-old child or an average-size adult male walking across a street and being struck from the side by an oncoming vehicle traveling at 40 km/hr (25 mph). This speed was selected by the GTR working group in the mid-2000s and is used as the basis for all subsequent international pedestrian regulations. It is also the target speed of all other NCAP procedures. The speed of 40 km/h (25 mph) was selected in part because the majority of pedestrian collisions occur at this speed or less. Though fatalities typically occur at higher speeds (70 km/h (43.5 mph) on average), a test speed above 40 km/h (25 mph) is not warranted due to the changing dynamics of a pedestrian-vehicle interaction as collision speeds

increase. For pedestrian-related crashes above 40 km/h (25 mph), an initial hood-to-torso interaction takes place in which the pedestrian tends to slide along the hood such that the head impact overshoots the hood and windshield. Moreover, the practicability of designing a vehicle front-end to achieve a high rating becomes increasingly difficult due to energy dissipation required as the impact increases.

The first point of contact occurs between the front-end of the vehicle and the lateral aspect of an adult pedestrian's leg near the knee region. As the lower leg becomes fully engaged with the vehicle front-end, contact is made between the leading edge of the hood and the lateral aspect of the pedestrian's pelvis or upper leg. Then, as the lower leg is kicked forward and away from the front-end of the vehicle, the pedestrian's upper body swings abruptly downward towards the hood whereupon the head strikes the vehicle. Depending on the size of the pedestrian and vehicle, the head strikes either the hood or the windshield.

When colliding with high profile vehicles, the pedestrian's pelvis engages early with the vehicle's front structure. The upper body then rotates about the pelvis while wrapping around the hood. When a pedestrian is hit by a low profile vehicle, only his/her lower leg is engaged by the vehicle's front structure and the head is likely to be projected onto the hood or windshield as the whole body rotates. The dynamic tests included in this pedestrian protection assessment program that the agency intends to include in this NCAP upgrade would account for both low and high profile vehicle impact scenarios.

The targeted walking posture is one in which a pedestrian is side-struck. This posture was chosen because it represents one of the more common interactions between vehicles and

pedestrians.[219] The side-struck posture is also regarded as "worst case" scenario for pedestrians (as in most likely to result in serious injury or death), which is supported by a recent study commissioned by the E.U.,[220] and the particulars for impact angle and impact velocity have been developed for that posture. The headforms used in the dynamic tests are hemispherical with no geometric characteristics for the face, which is beneficial in that the test procedure is generalized to mimic any head-to-hood/windshield interaction such as one resulting from a collision to a pedestrian who is struck from the rear while walking along the shoulder of the road.

The agency plans to conduct this pedestrian safety assessment program through a series of dynamic tests in which impactors are launched into the front-end of a stationary vehicle. Three different types of impactors, which are described in UNECE Regulation No. 127, "Pedestrian protection," would be used to assess the front end of a vehicle:

- Headforms – Two separate hemispherical headforms are used to assess the safety performance of the hood, windshield, and A-pillar against a head injury to the pedestrian. One headform representing the head of an adult and the other the head of a 6-year-old child. Both measure 165 mm (6.5 in) in diameter and each has three parts: a main hemisphere, a vinyl covering, and an end plate. A triaxial arrangement of accelerometers is mounted within each. Though they look similar and their diameters are identical, the headforms are not the same. The adult headform is 4.5 kg (9.9 lb) and the child headform is 3.5 kg (7.7 lb). The injury risk associated with the headform measurement is based on HIC – a function of the tri-axial linear acceleration, which is well established and used in

[219] Neal-Sturgess, C. E., Carter, E., Hardy, R., Cuerden, R., Guerra, L., & Yang, J., "APROSYS European In-Depth Pedestrian Database," The 20th International Technical Conference on the Enhanced Safety of Vehicles, 2007.
[220] Soni, A., Robert, T., & Beillas, P. (2013), "Effects of Pedestrian Pre-Crash Reactions on Crash Outcomes during Multi-body Simulations," 2013 IRCOBI Conference, Paper No. IRC-13-92.

numerous occupant protection FMVSSs where HIC of 1000 represents a 48-percent risk of skull fracture.[221]

- Upper Legform – The upper legform is used to measure how well the hood leading edge (or the area near the junction of the hood and grille) can protect a pedestrian against a hip injury and potentially child head or thorax injury. The upper legform impactor is a rigid, foam-covered device, 350 mm (13.8 in) long with a mass of 9.5 kg (20.9 lb). The front member is equipped with strain gauges to measure bending moments in three positions. Two load transducers measure individually the forces applied at either end of the impactor. This test was developed by the European Experimental Vehicles Committee (EEVC) in the working group (WG) 7, 10, and 17. The pelvis/hip injury risk associated with the upper legform measurements was originally based on a series of crash reconstructions associating pelvis/hip injury with energy measurements.[222] [223] These injury risk functions were subsequently assessed in a number of studies prior to inclusion of this test in Euro NCAP.[224] [225] [226] [227]

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[221] Eppinger, R. H., Sun, E., Bandak, F., Haffner, M., Khaewpong, N., Maltese, M., Kuppa, S., Nguyen, T., Takhounts, E., Tannous, R., Zhang, R., & Saul, R. (1999), "Development of improved injury criteria for the assessment of advanced automotive restrain systems – II," National Highway Traffic Safety Administration, Washington, DC, November 1999.

[222] Lawrence, G., Hardy, B., & Harris, J. (1991). "Bonnet Leading Edge Subsystem Test for Cars to Assess Protection for Pedestrians." The 13th International Technical Conference on the Enhanced Safety of Vehicles.

[223] Janssen, E., "EEVC Test Methods to Evaluate Pedestrian Protection Afforded by Passenger Cars." The 15th International Technical Conference on the Enhanced Safety of Vehicles, 1996.

[224] Konosu, A. et al., "A Study on Pedestrian Impact Test Procedure by Computer Simulation." The 16th International Technical Conference on the Enhanced Safety of Vehicles, Paper Number 98-S10-W-19, 1998.

[225] Matsui, Y. et al., "Validation of Pedestrian Upper Legform Impact Test – Reconstruction of Pedestrian Accidents." The 16th International Technical Conference on the Enhanced Safety of Vehicles, Paper No. 98-S10-O-05, 1998.

[226] EEVC WG17 report (2002). "Improved Test Methods to evaluate pedestrian protection afforded by passenger cars".

[227] Snedeker, J. et al. (2003). "Assessment of Pelvis and Upper Leg Injury Risk in Car-Pedestrian Collisions: Comparison of Accident Statistics, Impactor Tests, and a Human Body Finite Element Model." 47th Stapp Car Crash Journal, p. 437-457.

- FlexPLI – A pedestrian leg impactor (known as FlexPLI) is used to assess the bumper areas's capability to protect a pedestrian from incurring an injury to the knee and lower leg. The FlexPLI consists of synthetic flesh and skin material that cover two flexible long-bone segments (representing the femur and tibia), and a knee joint. The assembled impactor has a mass of 13.2 kg (29.1 lb) and is 928 mm (36.5 in) long. Bending moments are measured at four points along the length of the tibia and three points along the femur. Three transducers are installed in the knee joint to measure elongations of the medial collateral ligament (MCL), anterior cruciate ligament (ACL), and posterior cruciate ligament (PCL). Knee ligament and bone fracture injury risk functions associated with FlexPLI ligament elongation and tibia bending moment measurements are detailed by Takahashi et al. (2012).[228]

These devices and their associated launching rigs are the same as those currently in use in all other international NCAP pedestrian test protocols. Thus, to the extent that U.S. manufacturers are testing vehicles using the test procedures for international NCAP programs, they already likely own these devices and have experience with the test protocols.

The contact areas, which include the vehicle front-end, the hood leading edge, the hood itself, and the windshield, are the main sources of injury.[229] Testing with the devices – the FlexPLI, the upper legform, and the headforms – would provide a means to establish separate safety assessment for each contact area, respectively. Multiple tests over the contact areas would be carried out with each device. In this manner, a grid pattern is formed over the entire front-end

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[228] Takahashi, Y., et al. (2012). Development of Injury Probability Functions for the Flexible Pedestrian Legform Impactor. SAE Paper No. 2012-01-0277.
[229] Mallory, A., et al. (2012), "Pedestrian injuries by source: serious and disabling injuries in the U.S. and European Cases," Proceedings of the 2012 AAAM Conference.

of the vehicle with safety scores established for each point. The scores are then combined to form an overall pedestrian safety score for the vehicle.

NHTSA estimates that including these test procedures in NCAP would have a positive impact on a significant portion of pedestrian injuries and fatalities. According to FARS and NASS General Estimates System (GES) 2012 data, there were 3,930 pedestrian fatalities and 65,000 pedestrian injuries that included a frontal (10 – 2 o'clock) impact with a vehicle. Figure VII-4 in Appendix VII indicates that 9 percent of fatalities (FARS 2012 curve) and 69 percent of injuries (GES 2012 curve) in 2012 occurred at or below a vehicle speed of 40 km/h (25 mph), which is the baseline used in Euro NCAP test procedures. When these percentages are applied to the total fatalities and injuries, the target populations are 354 [3,930*9%] fatalities and 44,850 [65,000*69%] injuries. NHTSA's most detailed collection of pedestrian crash information was the Pedestrian Crash Data Study (PCDS) from 1994-1998. As shown in Figure VII-4 in Appendix VII , PCDS indicated that 32 percent of fatalities and 78 percent of injuries occurred at 40 km/h or lower, which, when applied to 2012 FARS/GES totals, would result in higher target populations of 1,258 [3930*32%] fatalities and 50,700 [65,000*78%] injuries. Based on GES 2012 and PCDS data, speeds at which pedestrians are getting hit by vehicles today are not significantly different than impact speeds 20 years ago, which supports PCDS as a reasonable comparative dataset for examining the distribution of impact speeds where fatalities and injuries occur.[230] Thus, a reasonable range of target population for pedestrian-related crashes in the United States is in the range of 354 – 1,258 fatalities and 44,850 – 50,700 injuries.

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[230] Differences between the low (FARS/GES) and the high (PCDS) estimates are most likely attributed to the way impact speed is determined: as reported by police in FARS/GES and by NHTSA accident investigative methods in PCDS. Considering this, PCDS estimates might appear more genuine. On the other hand, the PCDS is not

D. Crash Avoidance Technologies

NHTSA believes the greatest gains in highway safety in coming years will result from widespread application of crash avoidance technologies. Accordingly, the agency seeks to expand the scope of the NCAP program to rate crash avoidance and advanced technologies that NHTSA believes have potential to reduce the incidence of motor vehicle crashes and incorporate those ratings into the star rating system. Currently, crash avoidance technologies are not included in the star safety rating and, instead, are listed as "Recommended Technologies" on NHTSA's *Safercar.gov* website. As of today, the agency identifies vehicles equipped with Forward Collision Warning, Lane Departure Warning, and Rearview Video Systems as the Recommended Technologies that meet certain performance requirements.[231] When revisions to the NCAP program were implemented, NHTSA chose not to include crash avoidance tests in the star safety ratings based, in part, on comments submitted by manufacturers, trade associations, consumer groups, public health groups, and public citizens.[232] Initial market research in 2008 was inconclusive, but later market research in 2012 suggested that consumers may have lacked sufficient knowledge about advanced technologies prompting NHTSA to delay the incorporation

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considered a representative sample of the entire population and may be biased toward lower speed collisions. This would have the effect of inflating PCDS estimates of collisions under 40 km/hr. Also, any general improvement over time in vehicle design for pedestrian protection would be reflected in the (new, lower) FARS/GES estimates. Thus, the ranges given above are appropriate high and low bounds.

[231] Initially, NHTSA identified vehicles equipped with Electronic Stability Control (ESC), Forward Collision Warning and Lane Departure Warning as the Recommended Technologies in the prior round of revisions to the NCAP program, which began with MY 2011. ESC is now a required safety system on vehicles with a gross vehicle weight rating of 10,000 pounds or less. Beginning with MY2014, ESC was removed from the list of Recommended Technologies and Rearview Video Systems was added.

[232] On January 25, 2007 (see 72 FR 3472), NHTSA announced a Public Meeting (held March 7, 2007) and requested comments on a report titled, "The New Car Assessment Program Suggested Approaches for Future Program Enhancements." Docket No. NHTSA-2006-26555 contains this report (file ID NHTSA-2006-26555-0005), the meeting transcript (file ID NHTSA-2006-26555-0093) and all of the comments, In the 2008 NCAP upgrade notice (73 FR 40016, 40033, July 11, 2008), the agency stated most [Public Meeting] commenters supported the proposal to implement a crash avoidance rating program. At that time, the agency decided to promote a selection of beneficial crash avoidance technologies and to defer implementation of a quantified rating system.

of crash avoidance technologies in the star rating.[233] These technologies are becoming increasingly available in the market, and as a result consumers are becoming more familiar with them. NHTSA believes that by the time the planned upgrade to NCAP becomes effective, consumers will have a better understanding of the potential benefits of advanced crash avoidance technologies, making their inclusion in the 5-star ratings valuable to consumers.

In the intervening years, NHTSA believes that certain crash avoidance technologies have reached a level of technological maturity and will provide tangible safety benefits at reasonable costs. Further, the agency believes that, although we have seen a rapid increase in the number of passenger vehicles equipped with an expanding number of crash avoidance systems, some of which could be attributed to inclusion as a Recommended Technology, we believe that incorporating crash avoidance technologies into the star safety rating would help ensure that they are adopted more similarly to the crashworthiness tests; that is, faster and in more vehicles.

Thus, the agency believes it is now appropriate to include certain crash avoidance technologies into the overall star rating system. NHTSA believes a star rating in particular is necessary for crash avoidance technologies because consumers are already familiar with the 5-star approach to safety, while simply listing the available technologies on the label would potentially provide information without useful context. This NCAP upgrade would include the following crash avoidance technologies into the star ratings system: (1) forward collision warning, (2) crash imminent braking, (3) dynamic brake support, (4) lower beam headlighting performance, (5) semi-automatic headlamp beam switching, (6) amber rear turn signal lamps, (7) lane departure warning, (8) rollover resistance, and (9) blind spot detection. Separately, NHTSA

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[233] In the 2012 follow-up quantitative study, "Insight to Action, Monroney Label Research Qualitative Research Report, August 24, 2012," the agency found that consumers lacked sufficient knowledge about advanced crash avoidance technologies.

also intends to assess two additional crash avoidance systems, (1) pedestrian automatic emergency braking and (2) rear automatic braking, but the performance safety assessment results of those systems would be part of the pedestrian protection rating category under this NCAP upgrade. Consistent with the established criteria outlined in the April 2013 notice,[234] the agency assessed whether the technology addresses a safety need; the system design is capable of mitigating the safety need; the technology provides safety benefit potential; and a repeatable test procedure exists. The agency reviewed available crash avoidance technologies and found the eleven crash avoidance technologies described in this RFC notice satisfy the established criteria.

Further, in contrast to a vehicle's crashworthiness performance, which can vary yet still provide a level of occupant protection, crash avoidance systems generally have a binary result: either they avoid the crash or they do not. As a result, the agency cannot use the range-based star ratings found in crashworthiness and can, instead, only say whether the crash avoidance system on a vehicle either passes or fails the test. However, the agency still wishes to distinguish within the vehicles that pass the test to ensure that the highest ratings are for the safest vehicles. To do so, we recommend that stars be based on two criteria: passing the test and prevalence of the technology within a given model line. Thus, if a vehicle model passes the test for a particular technology, it will get half credit if the technology is offered as an optional safety system and full credit if it is offered as standard for the model. The agency believes this is a reasonable approach because it allows the model to achieve a higher score if the specific vehicle being purchased has a particular technology, thus providing a benefit to that consumer, while incentivizing OEMs to more quickly expand the set of safety technologies available as standard safety equipment for

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[234] See 78 FR 20599, April 5, 2013.

particular model lines. We request comment on this approach, in particular concerning whether there are other ways to distinguish crash avoidance technology star ratings among different models.

The agency is aware of additional advanced safety applications and monitoring systems that are currently under development and, therefore, not ready for inclusion into the NCAP rating system at this time. These include intersection movement assist, lane keeping support, advanced automatic crash notification, driver alcohol detection system, and driver distraction guidelines. These are briefly discussed in this RFC notice. The agency notes that the current NCAP LDW test procedure includes supplemental tests for lane keeping support systems, which may be performed for informative purposes to expand NHTSA's knowledge of how such systems operate. While NHTSA believes that these systems are approaching the technical readiness and performance levels necessary before inclusion into the NCAP crash avoidance rating, NHTSA will consider them in the future as the technologies mature and more research becomes available.

Table 6 shows available crash avoidance technologies that NHTSA believes could mitigate each crash type, as well as the predominant pre-crash scenarios within each crash type. NHTSA defined and statistically described this pre-crash scenario typology for light vehicles (passenger car, sports utility vehicle, minivan, van, and light pickup truck) based on the 2004 GES crash database.[235] This typology consists of 37 pre-crash scenarios that depict vehicle movements and dynamics as well as the critical event occurring immediately prior to a crash. Excluding the "other" scenario, this pre-crash scenario typology represents about 99.4 percent of

[235] DOT HS 810 767 (April 2007), available at www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2007/Pre-Crash_Scenario_Typology-Final_PDF_Version_5-2-07.pdf.

all light-vehicle crashes.[236] The percentage shown below each crash type in the first column of Table 6 is the 2010 incidence rate for all motor vehicle crashes estimated based on a fairly straightforward examination of the data in NHTSA's two primary databases, FARS and GES.[237]

Table 6. Map of Crash Avoidance Technologies Anticipated to Mitigate Each Crash Type

[236] The scenario labeled "other" in the typology encompasses the remaining crashes that are coded as "Other," "Unknown," or "No Impact" in the Accident Type variable in the NASS crash database; possible scenarios may include hit-and-run, no driver present, non-collision incident and other non-specific or no-details scenarios.
[237] DOT HS 812 013 (revised May 2015), www-nrd.nhtsa.dot.gov/Pubs/812013.pdf.

		Crash Avoidance Technologies										
Crash Type (2010 Incidence)	Pre-Crash Scenario	FCW	CIB	DBS	Rear auto-braking	Lower beam	Beam switching	Amber turn	LDW	Blind Spot	Pedestrian AEB	Rollover Rating
Rear-end (29%)	Lead vehicle stopped	●	●	●				●				
	Lead vehicle decelerating	●	●	●				●				
	Lead vehicle moving at lower constant speed	●	●	●				●				
	Following vehicle making a maneuver							●				
	Lead vehicle accelerating	●	●	●								
Crossing Paths * (24%)	Vehicle(s) turning at non-signalized junctions											
	Straight crossing paths at non-signalized junctions											
	Left Turn Across Path/Opp. Dir. at signalized junctions							●				
	Left Turn Across Path/Opp. Dir. non-signalized junctions							●				
	Running red light											
	Running stop sign					●	●					
	Vehicle turning right at signalized junctions							●				
Road Departure (19%)	Road edge departure without prior vehicle maneuver					●	●		●			●
	Road edge departure with prior vehicle maneuver					●	●					
	Road edge departure while backing up											
	Evasive action with prior vehicle maneuver					●	●					●
	Evasive action without prior vehicle maneuver					●	●					●
Lane Change (12%)	Vehicle(s) changing lanes - same direction							●		●		
	Vehicle(s) turning - same direction							●		●		
	Vehicle(s) drifting - same direction								●	●		
	Vehicle(s) parking - same direction							●		●		
Animal (6%)	Animal crash without prior vehicle maneuver					●	●					
	Animal crash with prior vehicle maneuver					●	●					
Opposite Direction (2%)	Vehicle(s) making a maneuver - opposite direction						●	●				
	Vehicle(s) not making a maneuver - opposite direction								●			
Backing (2%)	Backing up into another vehicle				●							
Pedestrian (1%)	Pedestrian crash with prior vehicle maneuver				●	●	●				●	
	Pedestrian crash without prior vehicle maneuver				●	●	●				●	
Pedalcyclist (1%)	Pedalcyclist crash with prior vehicle maneuver				●	●	●					
	Pedalcyclist crash without prior vehicle maneuver				●	●	●					
Object (1%)	Object crash with prior vehicle maneuver	●			●	●	●					
	Object crash without prior vehicle maneuver	●	●	●	●	●	●					

* Crossing Paths crashes are anticipated to be mitigated by future crash avoidance technologies that are assisted by vehicle-to-vehicle communications.

As Table 6 shows, no one technology listed addresses all crash events. Collectively, the crash avoidance technologies listed, with the exception of amber rear turn signal lamps, would alert and better inform the driver about unsafe conditions surrounding the vehicle, and in some circumstances would automatically brake to avoid or mitigate a collision. As the agency works to quantify the individual and collective contributions of crash avoidance technologies, qualitative

interpretations of the information in Table 6 suggest that vehicles offering more safety advances would increase the opportunities to avoid crashes, including those involving pedestrians and pedalcyclists. Ideally, as future crash avoidance technologies emerge and are deployed, each crash type will have multiple technologies poised to respond in an effort to prevent or mitigate crashes. Some technologies may offer modest individual contributions compared to others, but each has a key role to play in the overall effort to prevent or mitigate crashes. The three lighting technologies are impactful to three-quarters of the crash scenarios listed. Warning technologies and AEB systems are expected to directly impact the incidence of approximately one-third of the crash scenarios listed. Rollover resistance has a narrow application to prevent untripped on-road rollovers and possibly mitigate roadway departure crashes; however, other crash avoidance technologies may contribute by helping to avoid a tripping mechanism thereby potentially preventing a rollover.

To eliminate data voids and to improve data collection in support of benefit estimate calculation and the NCAP crash avoidance rating, NHTSA seeks to collaborate with manufacturers to improve the value of the coded vehicle identification number (VIN) attributes to NHTSA, by indicating the presence of crash avoidance technologies. It is NHTSA's desire to identify crash avoidance technologies through a combination of characters available within the VIN to facilitate statistical analysis. NHTSA hopes to work with manufacturers to voluntarily make these changes. This effort would not alter any of manufacturers' current VIN requirements under Part 565. Manufacturers will continue to provide to NHTSA, as required by Part 565, a key that deciphers VIN information. Additionally, this crash avoidance information will not communicate system performance or directly inform the consumer. The safety rating of the Monroney label and the *Safercar.gov* website would remain the primary means for the agency to

communicate rating information to consumers. Title 49 CFR Part 565 requires a vehicle manufacturer to assign a unique VIN to each vehicle that it produces. The five characters in VIN positions 4 through 8 uniquely identify attributes of the vehicle. For passenger cars, the attributes are make, line, series, body type, engine type, and all restraint devices and their location. The characters utilized and their placement within the section may be determined by the vehicle manufacturer, but the specified attributes must be decipherable with information supplied by the vehicle manufacturer.

Separately, NHTSA is developing a software catalog called the NHTSA Product Information Catalog and Vehicle Listing (vPIC) to organize the VIN information for rapid access and decoding of information that is submitted by the vehicle manufacturers. Access to this catalog was made available recently to the public.[238]

We emphasize that NHTSA is not pursuing a change to the VIN requirement. The agency recognizes that capturing standard versus optional equipment for each VIN is a challenge. To address this challenge, the agency requests comment on whether to collaboratively pursue coding specific crash avoidance technologies and combinations into the VIN, which would be associated to the make, model, trim, and model year levels.

1. Emergency Braking: Warning and Automatic Systems

An Automatic Emergency Braking (AEB) system uses forward-looking sensors, typically radars and/or cameras, to detect vehicles on the roadway. When a rear-end crash is imminent, if the driver takes no action, such as braking or steering, or if the driver does brake but does not provide enough braking to avoid the crash, the system may automatically apply or supplement

[238] NHTSA Product Information Catalog and Vehicle Listing (vPIC) available at http://vpic.nhtsa.dot.gov.

the brakes to avoid or mitigate the rear-end crash. AEB systems feature technologies that provide forward collision warning (FCW) alerts, as well as crash imminent braking (CIB) and/or dynamic brake support (DBS), which are specifically designed to help drivers avoid, or mitigate the severity of, rear-end crashes. CIB systems provide automatic braking when forward-looking sensors indicate that a crash is imminent and the driver has not braked, whereas DBS systems provide supplemental braking when sensors determine that driver-applied braking is insufficient to avoid an imminent crash.

Approximately 1.7 million rear-end crashes occur each year.[239] Not all of these are expected to benefit from AEB technology in general. NHTSA has identified a target population that is the subset of these crashes that could potentially be avoided or mitigated by AEB systems. These crashes involve an estimated 2,700,000 persons per year, and a total annual cost of $47 billion. More than 400,000 people are injured and over 200 people are killed in rear-end crashes each year. The agency developed a detailed target population in a June 2012 research report, finding that 910,000 crashes per year could potentially be avoided or mitigated with FCW, CIB, and DBS systems (collectively referred to as AEB systems here).[240]

The agency intends to use a new crash avoidance rating scheme that would depart from the current NCAP checkmark for Recommended Advanced Technologies Features. AEB is one of the systems that would contribute to the crash avoidance rating system calculation. The evaluation metrics for AEB systems in the new NCAP rating would be pass-fail. If a vehicle satisfies the performance requirements for each test scenario, the vehicle would receive credit for

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[239] Automatic Emergency Braking System (AEB) Research Report, August 2014. Available at www.regulations.gov, Docket No. NHTSA-2012-0057-0037, page 9.
[240] Forward-Looking Advanced Braking Technologies Research Report, NHTSA, June 2012; available at www.regulations.gov, Docket No. NHTSA-2012-0057-0001.

being equipped with the technology. If an AEB system is offered as an optional safety technology, the vehicle model would receive half credit for this technology. If an AEB system is a standard safety technology, the vehicle model would receive full credit for this technology.

a. Forward Collision Warning (FCW)

NHTSA intends to include FCW in its NCAP crash avoidance rating. The agency intends to use the same test procedures for FCW that it is currently using for the Recommended Advanced Technology Features on *Safercar.gov*.

The FCW system is based on two components: a sensing system capable of detecting a vehicle in front of the subject vehicle, and a warning system sending a signal to the driver. The sensing system consists of forward-looking radar, lidar, camera systems, or a combination thereof. The sensor data are digitally processed by a computer software algorithm that determines whether an object it has detected poses a safety risk (e.g., is a motor vehicle, etc.), determines if an impact to the detected vehicle is imminent, decides if and when a warning signal should be sent to the driver, and finally, sends the warning signal. The warning may be a visual signal, such as a light on the dash, an audio signal, such as a chime or buzzer, or a haptic feedback signal that applies rapid vibrations or motions to the driver. Based on NCAP testing, the typical haptic signals currently used for FCW systems are vibrations from the seat pan and/or steering wheel. The purpose of the FCW system is to alert the driver to the potential crash threat. The desired corrective action is to have the driver assess the situation, recognize the pending danger, and engage braking or steering to evade the possible rear-end crash event. FCW systems are typically the first technologies deployed in an AEB system currently available in many production motor vehicles.

The sensors, computers, algorithms, and warning systems used in FCW systems have evolved since these systems were first developed. Field experience and consumer feedback to vehicle manufacturers have reportedly enabled them to improve the reliability and consumer acceptance of these systems.

NHTSA previously determined the effectiveness of FCW technology from a field operational test (FOT) conducted between March 2003 and November 2004.[241] Sixty-six participants drove a total of about 163,000 km during the FOT, including 64,000 km with FCW. The analysis of this study reported a potential FCW effectiveness of 15 percent in reducing rear-end crashes. Additionally, this effectiveness was reported in the 2008 Federal Register notice which included FCW in the first phase of assessing crash avoidance technologies within the NCAP program.[242]

The agency recently revisited its calculations for the target population and the potential benefits estimates for FCW. The agency also calculated the overall effectiveness of all three AEB systems combined, which included CIB, DBS, and FCW. Although several studies show potential benefits, the estimated effectiveness of the systems varies from study to study. Further, these studies used prototype systems whose performance may vary from actual production systems. Additionally, the target population (those crashes that would be favorably affected by the installation and operation of these technologies) is not always well-defined and also varies considerably between studies. Preliminary benefits estimated based on three research vehicles with FCW, CIB, and DBS combined could prevent 94,000 – 145,000 minor injuries (AIS 1 - 2),

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[241] Evaluation of Automated Rear-End Collision Avoidance Systems. DOT HS 810 569, April 2006. Available at www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2006/HS910569.pdf.
[242] See 73 FR 40033. Docket No. NHTSA-2006-26555. Available at https://federalregister.gov/a/E8-15620.

2,000 – 3,000 (AIS 3 – 5) serious injuries, and save 78 – 108 lives annually.[243] In this analysis, FCW accounted for reducing 53,000 minor injuries (AIS 1-2), 1,260 serious injuries (AIS 3-5) and 35 fatalities.

The test procedure for FCW was originally published in 2008, and became part of NCAP in MY 2011. Minor updates have been placed in the docket for this program. For the 2016 MY NCAP evaluation, NHTSA will use the version titled "Forward Collision Warning System Confirmation Test, February 2013," which is available on the *Safercar.gov* website[244] and in the 2006 docket for Revisions to NCAP.[245] NHTSA will rely on this version to establish FCW system performance and inclusion in the agency's Recommended Advanced Technology Features on *Safercar.gov*.

The NCAP FCW test procedure consists of three scenarios selected because they simulate the most frequent rear-end scenarios. The subject vehicle (SV) used in this test is the vehicle being assessed. The principle other vehicle (POV) is a vehicle directly in front of the SV. In NHTSA's FCW performance evaluations, the POV is a production mid-size passenger vehicle.

In the first FCW scenario, the lead vehicle stopped (LVS) scenario, the SV encounters a stopped POV on a straight road. The SV is moving at 45 mph (72 km/h) and the POV is not moving, or 0 mph (0 km/h). To pass this test, the SV FCW alert must be issued when the time-to-collision (TTC) is at least 2.1 seconds. In the second FCW test, the lead vehicle decelerating (LVD) scenario, the SV follows the POV traveling on a straight, flat road at a constant speed of 45 mph (72 km/h) and a constant time gap. Then the SV encounters a decelerating POV braking

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[243] Forward-Looking Advanced Braking Technologies Research Report, NHTSA, DOT, June 2012. Available at www.regulations.gov, NHTSA-2012-0057-0001.
[244] Available at www.safercar.gov/Vehicle+Shoppers/5-Star+Safety+Ratings/NCAP+Test+Procedures.
[245] See www.regulations.gov, Docket No. NHTSA-2006-26555-0134.

at a constant deceleration of 0.3g. In order to pass this test, the FCW alert must be issued when TTC is at least 2.4 seconds. In the third FCW test, the lead vehicle moving (LVM) scenario, the SV encounters a slower-moving POV. Throughout the test, the SV is driven at 45 mph (72 km/h) and the POV is driven at a constant speed of 20 mph (32 km/h). In order to pass this test, the FCW alert must be issued when TTC is at least 2.0 seconds. All of these tests are conducted on a straight, high-quality surface test track. The relative speeds and times to collision are calculated using a differential global positioning system (GPS) installed in each of the two vehicles. The tests are conducted using two professional drivers. If the FCW system fails to alert the rear driver within the required time, the driver of the SV steers away to avoid a collision.

The FCW test scenarios directly relate to NHTSA crash data. These scenarios were developed for NCAP and added to the program in MY 2011. The scenarios were analyzed again in the development of the CIB and DBS test programs.[246] NHTSA data indicates LVS scenario in which the struck vehicle was stopped at the time of impact occurred in 64 percent of the rear-end crashes. The LVD scenario in which the struck vehicle was decelerating at the time of impact occurred in 24 percent of the rear-impact crashes. The LVM scenario in which the struck vehicle was moving at a constant but slower speed, compared to the striking vehicle occurred in 12 percent of the rear-end crashes.

The time-to-collision criteria used in each scenario represents the estimated time that would be needed for a driver to perceive a pending crash, discern the correct action to take, and

[246] See www.regulations.gov, Docket No. NHTSA-2012-0057-0037, page 10.

take the mitigating action.[247] NHTSA believes that the alerts are sufficient for a driver to react and avoid many of these rear-end crashes.

The agency seeks comments on whether to only award FCW credit if the SV is equipped with a haptic FCW.

b. Crash Imminent Braking (CIB)

NHTSA intends to include CIB in its overall crash avoidance rating for NCAP. CIB is a crash avoidance system that uses information from forward-looking sensors to determine whether a crash is imminent and whether it is appropriate to automatically apply the brakes. CIB systems are designed to activate automatically when a vehicle (the SV) is about to crash into the rear of another vehicle (the POV) and the SV's driver makes no attempt to avoid the crash. The systems typically consider whether the SV driver has applies the brakes and/or turned the steering wheel before intervening.

Current CIB sensor systems include radar, lidar, and/or vision-based camera sensors capable of detecting objects in front of the vehicle. Although some CIB systems currently in production can detect objects other than vehicles, NCAP test procedures would test the capability of systems to detect and activate only for vehicles in front of the subject vehicle. NHTSA is not planning to test a system's ability to detect and brake for other objects at this time. NHTSA believes that it will be able to accommodate alternative sensing methods in the future with minor test set-up modifications.

Pedestrian AEB systems are discussed later in this RFC notice. NHTSA does not plan to consider the capability of crash avoidance systems to detect and respond to other objects, such as

[247] The time-to-collision criteria were examined in a NHTSA FCW performance evaluation. See www-nrd.nhtsa.dot.gov/pdf/esv/esv21/09-0561.pdf.

animals or road obstructions in this NCAP upgrade. However, NHTSA encourages vehicle manufacturers to include detection of other objects in their CIB algorithms to avoid these other crash types.

CIB systems typically rely on the same forward-looking sensors used by FCW. NHTSA testing indicates CIB interventions generally occur after the FCW alert has been issued, although NHTSA has found some interventions to be coincident. The amount of braking authority varies among manufacturers, with several systems achieving maximum vehicle deceleration just prior to impact.

CIB is one of the earliest generations of automatic braking technologies. When an object in front of the forward-moving SV is detected, a computer software algorithm reviews the available data from the input signal of the sensing system. If the algorithm determines that a rear-end crash with another motor vehicle is imminent, then a signal is sent to the electronic brake controller to automatically activate the SV brakes.

The agency tentatively found that if CIB functionality is installed on all light vehicles without other AEB systems (i.e., FCW and DBS), it could potentially prevent approximately 40,000 minor-to-moderate injuries (AIS levels 1 and 2), 640 serious-to-critical injuries (AIS levels 3 – 5) and save approximately 40 lives, annually.[248] Crash severity is often characterized by the speed differential associated with the collision. It is a measure of the difference in velocity of the striking and struck vehicles just before and just after the impact occurs. The reduction in injuries ascribed to CIB without other AEB systems was estimated using injury risk versus delta-v curves that have been previously used by the agency for its light vehicle tire pressure monitoring system. NASS-CDS police-reported estimates of tow-away crashes were adjusted to

[248] See www.regulations.gov, Docket No. NHTSA-2012-0057-0037, page 16.

reflect all police-reported rear-impact crashes. At this time, all production CIB systems provide an FCW warning before the CIB system automatically applies the brakes. Therefore, safety benefits from CIB would be incremental to the benefits from an FCW alert.

To evaluate CIB (and the DBS mentioned below) on the test track, NHTSA developed the Strikeable Surrogate Vehicle (SSV), a surrogate vehicle modeled after a small hatchback car and fabricated from light-weight composite materials including carbon fiber and Kevlar®. The SSV appears as a "real" vehicle to the sensors used by contemporary CIB systems. For NCAP CIB tests, the agency intends to use the SSV as the POV.[249]

NHTSA's current CIB test procedure is comprised of three scenarios similar to the FCW scenarios (for a total of 4 tests) and one false-positive test (conducted at two speeds). For this NCAP upgrade, the agency intends to use the CIB test procedure specified in the recent AEB final decision notice.[250] In the LVS test, the SV approaches a stopped POV at 25 mph (40.2 km/h). In the LVM test, two SV/POV speed combinations would be used; first, the SV would be driven at 45 mph (72.4 km/h) toward a POV traveling at 20 mph (32.2 km/h); and second, the SV would be driven at 25 mph (40.2 km/h) toward a POV traveling at 10 mph (16.1 km/h). In the LVD test, the SV and POV would both be driven at 35 mph (56.3 km/h) with an initial headway of 45.3 ft (13.8 m), and then the POV would decelerate at 0.3g. In the Steel Trench Plate (STP) False Positive Test, two test speeds would be used; the SV would be driven over a 8 ft x 12 ft x 1 in (2.4 m x 3.7 m x 25 mm) steel trench plate at 45 mph (72.4 km/h) and 25 mph (40.2 km/h). Each scenario would be run up to seven times. To pass the NCAP performance criteria, the SV would need to pass five out of seven trials, and pass all six tests.

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[249] See www.regulations.gov, Docket No. NHTSA-2015-0006-0024, AEB Final decision notice.
[250] Ibid.

The CIB test scenarios directly relate to NHTSA crash data. Rear-end crashes are coded within the NASS-GES into the three major categories that denote the kinematic relationship between the striking and struck vehicle: LVM, LVD, and LVS. NHTSA's analysis of the crash data in support of the June 2012 research report on CIB systems showed that the target population of rear-end crashes (average during the years 2005 through 2009) was approximately 64 percent LVS scenarios, 24 percent LVD scenarios, and 12 percent LVM scenarios.[251]

For CIB, the NCAP performance criteria are speed reductions. Nominally, the magnitude of the speed reduction assigned to each test scenario corresponds to an effective deceleration of 0.6g from a TTC of 0.6 seconds. In the case of the CIB false positive tests, the performance criteria is a non-activation, where the SV must not achieve a peak deceleration equal to or greater than 0.5g at any time during its approach to the steel trench plate. These criteria were developed using NHTSA test data collected during 2011, and were intended to promote safety-beneficial and attainable performance.

The metrics include:

Table 7: CIB Test Metrics

Test Scenarios	Speed (mph)		Criterion
	Subject Vehicle	Surrogate target vehicle	
Lead Vehicle Stopped	25	0	≥ 9.8 mph (15.8 km/h)
Lead Vehicle Moving	45	20	≥ 9.8 mph (15.8 km/h)
Lead Vehicle Moving	25	10	Crash Avoided
Lead Vehicle Decelerating	35	35	≥ 10.5 mph (16.9 km/h)
Steel Trench Plate	45	Not applicable	No Activation

[251] See www.regulations.gov, NHTSA-2012-0057-0001.

			(Deceleration of $\leq 0.5g$)
Steel Trench Plate	25	Not applicable	No Activation (Deceleration of $\leq 0.5g$)

If all tests are passed, the vehicle would receive credit for having the CIB system as calculated in the Crash Avoidance rating system calculation. If CIB is offered as an optional safety system, the vehicle model would receive half credit for this system. If CIB is offered as standard safety system, the vehicle model would receive full credit for this system.

c. Dynamic Brake Support (DBS)

DBS applies supplemental braking in situations in which the system has determined that the braking applied by the driver is insufficient to avoid a collision. Typically, DBS relies on information provided by forward-looking sensor(s) to determine when supplemental braking should be applied. FCW most often works in concert with DBS by first warning the driver of the situation and thereby providing the opportunity for the driver to initiate the necessary braking. If the driver's brake application is insufficient, DBS provides the additional braking needed to avoid or mitigate the crash.

DBS is similar to CIB; the difference is that CIB activates when the driver has not applied the brake pedal, and DBS will supplement the driver's brake input. When an object in front of the forward-moving SV is detected, a computer software algorithm reviews the available data from the input signal of the sensing system. If the algorithm determines that a collision with an object in front of the SV is imminent and that the driver has applied the brakes, but not adequately, a signal is sent to the electronic brake controller. Then the brake system automatically provides additional braking.

DBS differs from a traditional brake assist system used with the vehicle's foundation brakes. With the foundation brakes, a conventional brake assist system applies additional braking by automatically increasing the brake power boost when the system identifies that the driver is in a panic-braking situation based on the driver's brake pedal application rate or some other means of sensing that the driver is in an emergency braking situation. This results in more pedal travel for the same braking force applied by the driver. DBS uses the forward-looking sensor information to determine that additional braking is needed, unlike conventional brake assist, which uses the driver's brake pedal application rate to determine that the driver is attempting to initiate emergency braking but may not be strong enough to fully apply the brakes.

While CIB and DBS are applicable to the same crash scenarios, the target population for CIB is a group where the driver does not apply the brakes before a crash. With DBS, the driver has braked insufficiently, and CIB is designed to address scenarios in which the driver has failed to brake. Using the assumptions previously defined in the AEB paragraph and applying them to the target population, the agency tentatively found that if DBS functionality alone is installed on all light vehicles, it could potentially prevent approximately 107,000 minor/moderate injuries (AIS 1 – 2), 2,100 serious-to-critical injuries (AIS 3 – 5), and save approximately 25 lives, annually. The safety benefits from DBS would be incremental to the benefits from an FCW alert.

The DBS test scenarios directly relate to NHTSA crash data. The previously described three major rear-impact crash categories that denote the kinematic relationship between the striking and struck vehicle are LVM, LVD, and LVS. NHTSA's analysis of the crash data in support of the June 2012 research report on CIB and DBS systems showed that the target

population was approximately 64 percent LVS scenarios, 24 percent LVD scenarios, and 12 percent LVM scenarios of rear-impact crashes.[252]

Similar to CIB, NHTSA intends to use the SSV as the POV to evaluate the DBS system on a test track. Also, like CIB, the agency intends to use the DBS test procedure specified in the recent AEB final decision notice. In the NCAP assessment, the DBS and the CIB systems would be evaluated separately, however, the DBS test procedures are nearly equivalent to the CIB test procedures. The DBS test brake application would be conducted with the use of a mechanical brake applicator, rather than a human test driver. Each scenario would be run up to seven times. To pass the NCAP performance criteria, the subject vehicle would need to pass five out of seven trials, and pass all the scenarios.

The DBS performance criteria for the LVS, LVM, and LVD scenarios specify that the SV must avoid contact with the POV. In the case of the DBS false positive tests, the performance criterion is a non-activation, where the SV must not achieve a peak deceleration ≥ 150 percent greater than that achieved with the vehicle's foundation brake system alone during its approach to the steel trench plate. If all tests are passed, the vehicle would receive credit for having the technology, as calculated in the Crash Avoidance rating system calculation. If DBS is offered as an optional safety system, the vehicle model would receive half credit for this system. If DBS is offered as standard safety system, the vehicle model would receive full credit for this system.

2. Visibility Systems

NHTSA intends to include three lighting safety features in this NCAP upgrade: lower beam headlighting performance, semi-automatic headlamp beam switching between upper and

[252] See www.regulations.gov, NHTSA-2012-0057-0001.

lower beams, and amber rear turn signal lamps. Guided by the limited data that exist, the agency believes that these visibility systems offer positive safety benefits with minimal burden to the manufacturers.

a. Lower Beam Headlighting Performance

To assist driving in darkness, FMVSS No. 108 requires passenger cars and trucks to have a headlighting system with upper beam and lower beam headlamps. While FMVSS No. 108 establishes a minimum standard for headlamp performance which has resulted in reduced injuries and fatalities, NHTSA believes that lower beam headlamp performance beyond the minimum requirements of FMVSS No. 108 will result in additional safety benefits.

The FARS database shows 47 percent (14,190 of 30,057) of the fatal crashes in 2013 were attributed to the light condition categories of dark – lighted, dark – not lighted, and dark – unknown lighting.[253] Specifically for pedestrians, the FARS database shows 71 percent (3,340 of 4,704) of the fatal crashes involving pedestrians in 2013 were attributed to the light condition categories of dark – lighted, dark – not lighted, and dark – unknown lighting. In 2013, 4,735 pedestrians were killed in traffic crashes, representing 14 percent of all fatalities that year. Pedestrians are at a higher risk of injury or fatality during darkness than they are during times of higher ambient illumination.[254] Sullivan and Flannagan (2001) concluded that the risk of pedestrian deaths is substantially greater in darkness, and that risk difference appears to increase continuously with increased traffic speed. Taking these two factors together, the agency predicts that increased vehicle luminance will reduce the risk of pedestrian fatalities at night. As shown in

[253] FARS Database Query Tool available at www-fars.nhtsa.dot.gov//QueryTool/QuerySection/SelectYear.aspx .
[254] Sullivan, J. M. & Flannagan, M. J. (2001). Characteristics of Pedestrian Risk in Darkness (UMTRI-2001-33).

Table 6, the lower beam headlighting performance maps to prevent or mitigate 13 of the 32 crash scenarios, including both pedestrian crash scenarios.

While extended illumination distance may better inform drivers so as to avoid striking pedestrians, this additional light could have unintended consequences if it is not properly controlled to limit glare. As such, the test procedure presented in Appendix VIII of this RFC notice grades a vehicle's headlighting system's lower beams for seeing light far down the road, but reduces the score for a headlighting system that produces glare beyond 0.634 lux, measured at a distance of 60 m (197 ft) and at a height of 1000 mm (39.7 in) above the road. Unlike the current test procedure for the FMVSS No. 108 requirement that evaluates a headlamp in a laboratory, this NCAP test would evaluate the headlighting system as installed on the vehicle. In order to support reproducibility of the test results, the headlighting system would be measured using seasoned bulbs and the headlamps would be aimed according to the manufacturer's recommendation prior to conducting the test. Five levels of performance would be established based on the measurement of five illuminance meters located 75 to 115 meters (246 ft to 377 ft) (spaced 10 m (32.8 ft) apart) forward of the vehicle. The level of performance would be established based on the lower beam headlighting system's ability to provide 3.000 lux of light to each of the five detectors. If all five detectors are illuminated to at least 3.000 lux and the glare detector is illuminated at less than 0.634 lux, the headlighting system would receive full credit within the final crash avoidance rating. If the glare meter is illuminated beyond 0.634 lux, the headlighting systems scoring would be reduced as detailed in the test procedure (see the docket, Appendix VIII).

b. Semi-automatic Headlamp Beam Switching

NHTSA intends to include semi-automatic headlamp beam switching in its crash avoidance NCAP rating because the agency believes it could lead to reductions of injuries and fatalities, particularly for pedestrians during darkness. FMVSS No. 108 requires each vehicle to have the ability to switch between lower and upper beam headlamps. As an option, a vehicle may be equipped with a semi-automatic device to switch between the lower and upper beam, which means the vehicle may automatically switch the headlamps from upper to lower beams and back based on photometric sensors installed as part of the semi-automatic beam switching system. While these systems switch the beams automatically, they are not fully-automatic in that they must allow the driver to have control of the system and manually switch beams based on the driver's input. The photometric design of the upper beam headlamp is optimized to provide long seeing distance. However, upper beam headlamps provide limited protection to other roadway users against glare. Therefore, properly switching between the upper and lower beam headlamps maximizes the overall seeing distance when driving at night without causing glare. While state laws often impose driver upper beam restrictions (situations in which the upper beam cannot be used), there is very little information available to drivers to help them determine when to safely use upper beam headlamps.

Based on studies indicating that the upper beam headlamps are used only 25 percent of the time in situations for which they would be useful without creating glare,[255] NHTSA intends to include semi-automatic headlamp beam switching in this NCAP upgrade. As discussed previously in the lower beam headlighting performance section, the agency believes that among other crash types, pedestrian fatalities that occur under dark-not-lighted conditions may be

[255] Mefford, M. L., Flannagan, M. J., & Bogard, S. E. (2006). Real-World Use of High-Beam Headlamps (UMTRI-2006-11).

reduced or mitigated by additional proper use of the upper beam. As shown in Table 6, semi-automatic headlamp beam switching maps to prevent or mitigate 14 of the 32 crash scenarios.

Semi-automatic headlamp beam switching was reported as optional or standard for approximately 52 percent of the "trim lines" (sub-models) listed in the 2016 Buying a Safer Car letter by the manufacturers. Since most semi-automatic headlamp beam switching devices activate above a minimum driving speed and react dynamically to the environment, primarily to other vehicles on the roadway, a traditional, passive and stationary goniometer-based laboratory test procedure will not suffice for confirmation of beam switching operation. Therefore, NHTSA intends to use vehicle related static measurements including confirmation of manual override capability, automatic dimming indicator, and mounting height, as well as two vehicle maneuver tests to effectively produce the semi-automatic beam switching device response to a suddenly appearing vehicle representation in a straight road scenario. The first dynamic test simulates an approaching vehicle, and the second dynamic test simulates a preceding vehicle. This test procedure will confirm that the driver has both the information necessary and the responsibility for final control of headlamp beam switching.

c. Amber Rear Turn Signal Lamps

In 2009, NHTSA studied the effect of rear turn signal color as a means to reduce the frequency of passenger vehicles crashes.[256] Specifically, the agency analyzed whether amber or red turn signals were more effective at preventing front-to-rear collisions when the rear-struck (leading) vehicle was engaged in a maneuver (i.e., turning, changing lanes, merging, or parking) where turn signals were assumed to be engaged.

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[256] Allen (2009). National Highway Traffic Safety Administration (DOT HS 811 115). Available at www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2009/811115.pdf.

FMVSS No. 108 requires each vehicle to have two turn signals on the rear of the vehicle. The regulation provides manufacturers the option of installing either amber (yellow) or red rear turn signals with applicable performance requirements for each choice. To avoid imposing an unreasonable cost to society, NHTSA's lighting regulation continues to allow for the lower cost rear signal and visibility configurations that meet these requirements. Typically, the lower cost configuration includes one combination lamp on each of the rear corners of the vehicle, containing a red stop lamp, a red side marker lamp, a red turn signal lamp, a red rear reflex reflector, a red side reflex reflector, a red tail lamp, and a white backup lamp. (A separate license plate lamp is typically the most cost effective choice for vehicles rated in the NCAP information program). Such a configuration can be achieved using just two bulbs and a two color (red and white) lens.

The purpose of FMVSS No. 108 is to reduce crashes and injuries by providing adequate illumination of the roadway and by enhancing the visibility of motor vehicles on public roads so that their presence is perceived and their signals understood, both in daylight and in darkness or other conditions of reduced visibility. While the red rear turn signal lamp configuration provides a minimum acceptable level of safety, the agency believes improved safety (measured as the reduction in the number of rear-end crashes that resulted in property damage or injury) can be achieved with amber rear turn signal lamps at a cost comparable to red rear turn signal lamp configurations. This is supported by the observation of vehicle manufacturers changing the rear turn signal lamp color for a vehicle model from one year to the next, as was discussed in NHTSA Report DOT HS 811 115. The results of this NHTSA study estimated the effectiveness of amber rear turn signal lamps, as compared to red turn signal lamps, decrease the risk of two-vehicle,

rear-end crashes where the lead vehicle is turning by 5.3 percent.[257] That study was designed around the concept of "switch pairs," in which make-models of passenger vehicles switched rear turn signal color. The crash involvement rates were computed before and after the switch. NHTSA estimates that there are roughly 68,550 injury rear-end crashes annually in which the lead vehicle is changing direction. As shown in Table 6, rear amber turn signal lamps map to prevent or mitigate 11 of the 32 crash scenarios listed. For these reasons, NHTSA intends to include amber rear turn signals in this NCAP upgrade.

A test procedure for amber turn signal lamps exists in FMVSS No. 108. For this program, NHTSA intends to use only the Tristimulus method (FMVSS No. 108 S14.4.1.4) for determining that the color of the rear turn signal lamp falls within the range of allowable amber colors. As is the case with the regulation, the color of light emitted must be within the chromaticity boundaries as follows:

$y = 0.39$ (red boundary)

$y = 0.79 - 0.67x$ (white boundary)

$y = x - 0.12$ (green boundary)

If the motor vehicle is equipped with amber rear turn signals meeting these requirements, the agency intends to give credit in the crash avoidance rating for these vehicles.

3. Driver Awareness and Other Technologies

NHTSA believes crash avoidance warning systems have the potential to improve driver performance and reduce the incidence and severity of common crash situations. Analysis of manufacturer reported make/model features reveals that warning systems are increasingly

[257] Allen (2009). National Highway Traffic Safety Administration (DOT HS 811 115). Available at www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2009/811115.pdf.

offered in passenger vehicles, possibly the result of heightened levels of interest or demand by the consumer.

a. Lane Departure Warning (LDW)

NHTSA intends to include LDW in its crash avoidance rating for this NCAP upgrade. Currently, LDW is one of the 'Recommended Technologies' listed on the NHTSA website *Safercar.gov*.[258] The LDW system is a driver aid that uses vision-based sensors to detect lane markers ahead of the vehicle. The LDW system alerts the driver when the vehicle is laterally approaching a lane boundary marker, as indicated by a solid line, a dashed line, or raised reflective indicators such as Botts dots. The LDW system may produce one or more user interfaces, such as an auditory alert or haptic feedback to the driver, and is often accompanied with a visual indicator or display icon in the instrument panel to indicate which side of the vehicle is departing the lane.

Vehicle-based LDW technology utilizes either GPS technology or forward- or downward-looking optical sensors. A GPS system compares position data with a high resolution map database to determine the vehicle location within the lane. An optical sensor system uses a forward looking or downward looking optical sensor with image processing algorithms to determine where the lane edge lines are located. If the turn signal is activated, the LDW system computer software algorithm considers the driver to be purposefully crossing the lane boundary marker, and no alert is issued. LDW system performance may be adversely affected by precipitation (e.g., rain, snow, fog) and roadway conditions with construction zones, unmarked intersections, and faded, worn, or missing lane markings.

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[258] A video file and an animation file describing LDW are available at www.safercar.gov/staticfiles/safetytech/st_landing_ca.htm.

LDW systems are designed to help prevent crashes resulting from a vehicle unintentionally drifting out of its travel lane. For the light passenger-vehicle crashes considered over the period 2002-2006, the Advanced Crash Avoidance Technologies (ACAT) program performed around 15,000 simulations in order to set up the underlying virtual crash population; by optimizing driving scenario weights it was possible to produce a reasonable degree of fit to the actual (GES coded) crash population. ACAT estimated that a baseline set of 180,900 crashes annually in the United States could be reduced to about 121,600 with LDW in place, so that around 59,300 crashes might be prevented.[259] AAA reported that LDW systems activate when vehicle speeds are above 40 to 45 mph (64 to 72 km/h).[260] NHTSA crash data from the period 2004 to 2013 indicate that a lane departure maneuver was a precursor to approximately 40 percent of the fatal crashes involving a single vehicle.[261] NHTSA determined that a vehicle departed its lane as characterized by the database annotation of the relation to roadway as Off Roadway, Shoulder, or Median.[262] The agency believes additional benefits from LDW technology may contribute to the possible reduction in the number of head-on collisions.[263] [264]

The IIHS similarly estimated in a 2010 report that LDW systems could prevent as many as 7,500 fatal crashes, noting that while crashes in which vehicles drift off the road have a low incidence rate, they account for a large proportion of fatal crashes.[265] In addition to the numbers

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[259] DOT HS 811 405, Advanced Crash Avoidance Technologies (ACAT) Program – Final Report of the Volvo-Ford-UMTRI Project: Safety Impact Methodology for Lane Departure Warning – Method Development and Estimation of Benefits, October 2010. Available at www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2010/811405.pdf.
[260] AAA Status Report, Vol. 44, No. 10. November 18, 2009.
[261] FARS and GES.
[262] Ibid.
[263] www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Public%20Paper/SAE/2006/Barickman_LaneDepartuerWarning_final.pdf.
[264] IIHS, Status Report, Vol. 45, No. 5. May 20, 2010.
[265] Lund, A. Drivers and Driver Assistance Systems: How well do they match? 2013 Driving Assessment Conference, Lake George, NY. June 18, 2013.

NHTSA used in the 2008 NCAP upgrade notice,[266] the Highway Loss Data Institute (HLDI) estimates that LDW could apply in approximately 3 percent of police-reported crashes.[267] Three percent of the 2013 NHTSA estimated 5,687,000 police-reported crashes equates to 170,610 crashes that could potentially be reduced or mitigated with LDW crash avoidance technology.

NHTSA monitors and analyses the interaction and accumulation of vehicle alerts directed at drivers. Based on recently published technical papers describing consumer acceptance or preference of alert modality, the agency is aware that some drivers choose to disable the LDW system if they experience numerous alerts, thereby diminishing any safety benefit.[268] Additionally, the agency is concerned that multiple and overlapping alerts may create confusion for the driver regarding which safety system is being activated or engaged. Rather than require a specific alert modality for the LDW crash avoidance technology, the agency intends to re-define the LDW performance criteria such that the LDW alert may not occur when the lateral position of the vehicle is greater than +1.0 ft (+0.30 m) from the lane line edge to pass the planned NCAP test procedure. NHTSA would not consider the intensity of the haptic or the feedback delivery component (e.g., steering wheel or seat haptic) in determining whether or not a vehicle received credit for LDW in NCAP.

Development of LDW technology has evolved into lane keeping support (LKS) systems that actively guide the vehicle within the lane by counter steering. In the NCAP LDW assessment, an LKS steering wheel movement would be considered an acceptable LDW haptic alert.

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[266] LDW effectiveness of 6 – 11 percent was estimated from data included in NHTSA Report No. DOT HS 810 854, Evaluation of a Road Departure Crash Warning System, December 2007.
[267] IIHS Status Report, Vol. 47, No. 5. Special Issue: Crash Avoidance. July 3, 2012.
[268] Ibid.

The agency is also concerned about false activations and missed detections resulting from tar lines reflecting sun light or covered with water and other unforeseen anomalies, which would result in an unreliable driver warning. However, the LDW test procedure is not currently structured to address these concerns. Comments are requested on these issues.

LDW systems, as NHTSA currently defines them, only focus on lane departures while the vehicle is traveling along a straight line and does not account for technologies that look at curve speed warnings (CSW). CSW alerts the driver when he or she is traveling too fast for an upcoming curve. NHTSA crash data indicates off-roadway crashes occur substantially more often than crashes departing from the shoulder and median combined. NHTSA believes LDW has the potential to provide the driver with the vital sliver of time for rapid decision-making necessary to adjust and correct the vehicle direction prior to a road departure situation developing.

The agency intends to continue to use the current NCAP test procedure titled NCAP Lane Departure Warning and LKS Test Procedure for NCAP, [269] and requests comment on whether to revise certain aspects of the test procedures. The LDW test procedure provides the specifications for confirming the existence of LDW hardware. Specifically, it tests for the ability to detect lane presence, an unintended lane departure, LDW engagement, and LDW disengagement. The NCAP LDW tests are conducted at a constant test speed of 45 mph (72 km/h), in two different departure directions, left and right, using three different styles of roadway markings, continuous white lines, discontinuous yellow lines, and discontinuous raised pavement markers. Test track conditions are defined as a dry, uniform, solid-paved surface with high contrast line markings defining a single roadway lane edge. Each test series is repeated until five (5) valid tests are

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[269] Available at www.safercar.gov/Vehicle+Shoppers/5-Star+Safety+Ratings/NCAP+Test+Procedures.

produced. LDW performance is evaluated by examining the proximity of the vehicle with respect to the edge of a lane line at the time of the LDW alert.

Each test trial measures whether the LDW issues an appropriate alert during the maneuver in order to determine a pass or fail. In the context of this test procedure, a lane departure is said to occur when any part of the two dimensional polygon used to represent the test vehicle breaches the inboard lane line edge. The agency requests comments on whether a valid trial is considered a failure if the distance between the inside edge of the polygon to the lane line at the time of the LDW warning is outside –1.0 to +1.0 ft (–0.30 to +0.30 m), where a negative number represents post-line position, or if no warning is issued. This is a change from the current NCAP test procedure which specifies -1.0 to +2.5 ft (-0.30 to +0.75 m). The LDW system must satisfy the pass criteria for 3 of 5 individual trials for each combination of departure direction and lane line type (60%), and pass 20 of the 30 trials overall (66%). If more than five trials are deemed valid, the pass/fail criteria must be met for three of the first five valid trials. If LDW is offered as an optional safety system, the vehicle model would receive half credit for this system. If LDW is offered as standard safety system, the vehicle model would receive full credit for the system. Comments are requested on whether the agency should only award NCAP credit to LDW systems with haptic alerts.

b. Rollover Resistance

Rollover crashes are complex events that reflect the interaction of driver, road, vehicle, and environmental factors. The term "rollover" describes the condition of at least a 90-degree rotation about the longitudinal axis of a vehicle,[270] regardless of whether the vehicle ends up

[270] "Rating System for Rollover Resistance, An Assessment," Transportation Research Board Special Report 265, National Research Council.

laying on its side, roof, or even returning upright on all four wheels. Rollovers occur in a multitude of ways. The risk of rollover is greater for vehicles designed with a high center of gravity in relation to the track width. Driver behavior and road conditions are significant factors in rollover crash events. Specifically, the factors that strongly relate to rollover fatalities are: if it was a single-vehicle crash, if it was a rural crash location, if it was a high-speed roadway, if it occurred at night, if there was an off-road tripping/tipping mechanism, if it was a young driver, if the driver was male, if it was alcohol-related, if it was speed-related, if there was an unbelted occupant, and if an occupant was ejected.

i. Background

Rollover is one of the most severe crash types for light vehicles. In 2012, 112,000 rollovers occurred as the first harmful event, measuring 2 percent of the 5,615,000 police-reported crashes involving all types of motor vehicles. In 2012, single, light-vehicle rollovers accounted for 6,763 occupant deaths. This represented 20 percent of motor vehicle fatalities in 2012, 31 percent of people who died in light-vehicle crashes, and 46 percent of people who died in light-vehicle single-vehicle crashes.[271]

NHTSA describes rollovers as "tripped" or "untripped." In a tripped rollover, the vehicle rolls over after leaving the roadway due to striking a curb, soft shoulder, guard rail or other object that "trips" it. Crash data suggest approximately 95 percent of rollovers in single-vehicle crashes are tripped.[272] A small percentage of rollover events are untripped, typically induced by tire and/or road interface friction. Whether or not a vehicle rolls when it encounters a tripping mechanism is highly dependent upon the ratio of two vehicle geometric properties, referred to as

[271] DOT HS 812 016, available at www-nrd.nhtsa.dot.gov/Pubs/812016.pdf.
[272] See 68 FR 59251. Docket No. NHTSA-2001-9663, Notice 3. Available at https://federalregister.gov/a/03-25360

the Static Stability Factor (SSF). The SSF of a vehicle is calculated as one-half the track width, t, divided by the height of the center of gravity (c.g.) above the road, h; SSF = (t/2h). The inertial force that causes a vehicle to sway on its suspension (and roll over in extreme cases) in response to cornering, rapid steering reversals or striking a tripping mechanism, like a curb or the soft shoulder of the road, when the vehicle is sliding laterally, may be thought of as a force acting at the c.g. to pull the vehicle body laterally. A reduction in c.g. height increases the lateral inertial force necessary to cause rollover by reducing its leverage, and this is represented by an increase in the computed value of SSF. A wider track width also increases the lateral force necessary to cause rollover by increasing the leverage of the vehicle's weight in resisting rollover, and that advantage also increases the computed value of SSF. The factor of two in the computation (t/2h) makes SSF equal to the lateral acceleration at which rollover begins in the most simplified rollover analysis of a vehicle, which is represented by a rigid body without suspension movement or tire deflections.[273]

In 2001, the agency decided to use SSF to indicate rollover risk in a single-vehicle crash.[274] Additionally, in that notice, the agency introduced the rollover resistance rating as a means to quantify the risk of a rollover if a single-vehicle crash occurs. The agency emphasizes that this rating does not predict the likelihood of a rollover crash occurring only that of a rollover occurring given that a single vehicle crash occurs. In this rating system, the lowest rated vehicles (1 star) are at least 4 times more likely to rollover than the highest rated vehicles (5 stars).

The rollover rating that was included as part of NCAP was based on a regression analysis that estimated the relationship between single-vehicle rollover crashes and the vehicles' SSF

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[273] For further explanation see the description and Figure 1 at www.nhtsa.gov/cars/rules/rulings/Rollover/Chapt05.html.
[274] See 66 FR 3388. Docket No. NHTSA-2000-8298. Available at https://federalregister.gov/a/01-973.

using state crash data. The SSF is measured at a Vehicle Inertial Measurement Facility (VIMF).[275] NHTSA acquires vehicles and measures the height of the vehicle c.g. The VIMF consistently measures the c.g. height location of a particular vehicle using the stable pendulum configuration. The test facility must be capable of measuring the c.g. height location to within 0.5 percent of the theoretical height, typically the 3-dimensional computer generated solid model value of that vehicle. The track width is also measured on the same vehicle at this time. The risk of rollover originally calculated for the 2001 notice was based on a linear regression analysis of 220,000 single-vehicle crash events reported by 8 States (Florida, Maryland, Missouri, New Mexico, North Carolina, Ohio, Pennsylvania, and Utah).

Pursuant to the FY 2001 DOT Appropriations Act, NHTSA funded a National Academy of Science (NAS) study on vehicle rollover resistance ratings.[276] The study focused on two topics: whether the SSF is a scientifically valid measurement that presents practical, useful information to the public, and a comparison of the SSF versus a test with rollover metrics based on dynamic driving conditions that may include rollover events. NAS published their report at the end of February 2002.[277]

The NAS study found that SSF is a scientifically valid measure of rollover resistance for which the underlying physics and real-word crash data are consistent with the conclusions that an increase in SSF reduces the likelihood of rollover. It also found that dynamic tests should complement static measures, such as SSF, rather than replace them in consumer information on rollover resistance. The NAS study also made recommendations concerning the statistical

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[275] "The design of a Vehicle Inertial Measurement Facility," Heydinger, G. J. et al, SAE Paper 950309, February, 1995.
[276] Department of Transportation and Related Agencies Appropriations, 2001. Pub. L. 106-346 (Oct. 23, 2000).
[277] "Rating System for Rollover Resistance, An Assessment," Transportation Research Board Special Report 265, National Research Council.

analysis of rollover risk and the representation of ratings methodology. The two primary recommendations suggested using logistic regression rather than linear regression for analysis of the relationship between rollover and SSF, and a high-resolution representation of the relationship between rollover and SSF than is provided in the current 5-star program.

On October 14, 2003, NHTSA published a final policy statement outlining its changes to the NCAP rollover resistance rating.[278] Beginning with the 2004 model year, NHTSA combined a vehicle's SSF measurement with its performance in a dynamic "fishhook" test maneuver presented as a single rating. The fishhook maneuver is performed on a smooth pavement and is a rapid steering input followed by an over-correction representative of a general loss-of-control situation. This action attempts to simulate steering maneuvers that a driver acting in panic might use in an effort to regain lane position after dropping two wheels off the roadway onto the shoulder.

Additionally, the predicted rollover resistance ratings were reevaluated. Consistent with the NAS recommendations, the agency changed from a linear regression to a logistic regression analysis of the data. The sample size increased to 293,000 single-vehicle crash events, producing a narrow confidence interval on the repeatability of the relationship between SSF and rollover. In contrast, the linear regression analysis performed on the rollover rate of 100 make/models in each of the six States providing data, resulted in a sample size of 600. In addition, a second risk curve was generated for vehicles that experienced a tip-up in the dynamic fishhook test.

ii. Updates to the rollover NCAP SSF risk curve

Commenters to NHTSA's 2008 NCAP upgrade notice asked NHTSA to collect crash data on vehicles equipped with ESC in order to develop a new rollover risk model. In July 2008,

[278] See 68 FR 59250. Docket No. NHTSA-2001-9663, Notice 3. Available at https://federalregister.gov/a/03-25360.

the agency upgraded the NCAP program to combine the rollover rating with the frontal and side crash ratings, creating a single, overall vehicle rating.[279] No changes were made to the risk model at that time.[280] However, NHTSA received comments requesting that the agency collect this crash data to develop a new rollover risk model that better describes the rollover risk of all vehicles that reflects the real-world benefits of ESC.[281] To enhance its rollover program, the agency responded that they would continue to monitor the rollover rate for single-vehicle crashes involving ESC equipped vehicles.

The accumulation of crash data involving vehicles equipped with ESC has been slow. The 2003 regression analysis was based on 293,000 crash events. Up until recently, the agency had observed fewer than 10,000 crashes with ESC-equipped vehicles. Previously, NHTSA was not confident that it could accurately redraw the risk curves using such a small sample size. The agency now believes that it has accumulated enough data to see a narrower tolerance band adequate for use in a rating system.

According to the 2013 FARS, 7,500 vehicle occupants were killed in light-vehicle rollovers.[282] These 2013 rollovers accounted for 34.6 percent of the 21,667 fatalities in light vehicles that year. Of these 7,500 fatalities, 6,254 were killed in single-vehicle rollovers. NCAP provides a consumer information rating program articulating the risk of rollover, to encourage consumers to purchase vehicles with a predicted lower risk of a rollover. This information enables prospective purchasers to make choices about new vehicles based on differences in rollover risk and serve as a market incentive to manufacturers to design their vehicles with

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[279] See 73 FR 40021. Docket No. NHTSA-2006-26555. Available at https://federalregister.gov/a/E8-15620.
[280] See 73 FR 40032. Docket No. NHTSA-2006-26555. Available at https://federalregister.gov/a/E8-15620.
[281] See 72 FR 3475. Docket No. NHTSA-2006-26555. Available at https://federalregister.gov/a/E7-1130.
[282] Traffic Safety Facts 2012. DOT HS 812 032 available at www-nrd.nhtsa.dot.gov/Pubs/812032.pdf.

greater rollover resistance. The consumer information program also informs drivers, especially those who choose vehicles with poorer rollover resistance, that their risk of harm can be greatly reduced with seat belt use to avoid ejection. The program seeks to remind consumers that even the highest rated vehicle can roll over, but that they can reduce their chance of being killed in a rollover by about 75 percent just by wearing their seat belts.

NHTSA intends to update and recalculate the risk curve using ESC data collected from 20 States, and to transition the rollover risk rating into a new crash avoidance rating. In this new rollover scoring, NHTSA would not be changing the dynamic rollover test. The agency believes that embedding rollover into the crash avoidance rating is more appropriate since it targets rollover prevention and it also consolidates the message of reduced crash incidence. Rollover resistance would remain a significant component in the rating scheme, weighted based on its relative importance to overall vehicle safety. The details of how the crashworthiness rating is combined with the crash avoidance rating into an overall rating system are discussed in the rating section of this RFC notice.

The statistical model created in 2003 combined SSF and dynamic maneuver test information to predict rollover risk. The agency performed the Fishhook test on about 25 of the 100 make/model vehicles for which SSF was measured and substantial State crash data was available.[283] Eleven of the 25 vehicles tipped up[284] in the Fishhook maneuver that was conducted in the heavy condition with a 5-occupant load. All 11 vehicles had SSFs less than 1.20.

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[283] An Experimental Examination of 26 Light Vehicles Using Test Maneuvers That May Induce On-Road, Untripped Light Vehicle Rollover—Phase VI of NHTSA's Light Vehicle Rollover Research Program, NHTSA Technical Report, DOT HS 809 547, 2003.

[284] A "tip-up" occurs when the two vehicle wheels lift off the ground 2 inches during the Fishhook test.

At that time, the agency believed it was very unlikely that passenger cars would tip-up in the maneuver test because no tip-ups were observed in the passenger cars tested at the low end of the SSF range for passenger cars. To validate that assumption, the agency tested a few passenger cars each year at the low end of the SSF range. No tip-ups have been observed in the agency tests for any vehicle type since 2007. Therefore, the agency is unable to produce an estimate or a logistic regression curve based on tip/no-tip as a variable.

The rollover statistical model was populated with new data and used logistic regression analysis to update the rollover risk curve. The agency examined 20 State datasets for single-vehicle crashes involving vehicles equipped with ESC that occurred during 2011 and 2012. Data were reported by Delaware, Florida, Iowa, Illinois, Indiana, Kansas, Kentucky, Maryland, Michigan, Missouri, Nebraska, New Jersey, New Mexico, New York, North Carolina, North Dakota, Pennsylvania, Washington, Wisconsin, and Wyoming. The dataset was comprised of 11,647 single-vehicle crashes, of which 627 resulted in rollover. For 2011, NHTSA used data reported by each of the 20 States for single-vehicle crashes involving ESC-equipped vehicles; a summation of 5,429 crashes. For 2012, NHTSA used data reported by 10 States for single-vehicle crashes involving ESC-equipped vehicles; 6,218 crashes. Table 8 shows a summary of the 2011 and 2012 State dataset used for the logistic regression analysis.

Table 8. Summary of 2011 and 2012 State data used to generate the rollover risk curve

State	2011			2012		
	Non-Rollover	Rollover	Total	Non-Rollover	Rollover	Total
DE	29	2	31	88	2	90
FL	624	26	650	No data	No data	No data
IA	123	12	135	237	22	259
IL	319	19	338	No data	No data	No data
IN	283	0	283	723	17	740
KS	92	2	94	266	7	273
KY	211	17	228	464	50	514

MD	133	14	147	310	31	341
MI	619	34	653	1,344	74	1,418
MO	204	22	226	No data	No data	No data
NC	407	43	450	1,028	87	1,115
ND	17	4	21	No data	No data	No data
NE	67	4	71	213	13	226
NJ	503	18	521	1,199	43	1,242
NM	55	3	58	No data	No data	No data
NY	793	4	797	No data	No data	No data
PA	383	39	422	No data	No data	No data
WA	73	8	81	No data	No data	No data
WI	203	9	212	No data	No data	No data
WY	10	1	11	No data	No data	No data
Total	5,148	281	5,429	5,872	346	6,218

The new dataset included 197 different makes/models for which the SSF had been calculated within NCAP; the SSF ranged from 1.07 to 1.53. The new dataset contained two vehicle types, passenger cars and light truck vehicles, including pickup trucks, SUVs, and vans. To accomplish the rollover analysis, it is more appropriate to use the state dataset because it provides the ability to filter for ESC-equipped vehicles rather than the NHTSA FARS database, which is not sufficiently granular. FARS contains two data elements; rollover and rollover location. The rollover data element has attributes of no rollover, tripped rollover, untripped rollover, and unknown type rollover. The rollover location data element has attributes of no rollover, on roadway, on shoulder, on median/separator, in gore, on roadside, outside of trafficway, in parking lane/zone, and unknown. The State dataset distribution compares similarly to the FARS number of vehicles involved in fatal crashes with a rollover occurrence. Table 9 summarizes the 2011 and 2012 rollover data for the number of single-vehicle crashes for ESC-equipped vehicles by vehicle type. For comparison, Table 10 summarizes the number of vehicles involved in fatal crashes with a rollover occurrence by vehicle type, as reported in FARS. In the new rollover model dataset, pickup trucks appear to be slightly underrepresented and SUVs appear to be slightly overrepresented compared with the FARS data.

Table 9. Summary of 2011 and 2012 State data used to generate the rollover risk curve

Vehicle Type	Single-Vehicle Crashes (ESC-equipped Vehicles)			Number of Rollovers	Proportion, by Vehicle Type
	2011	2012	Total		
Passenger Car	2,803	3,280	6,083	262	42 %
Pickup	636	768	1,404	92	15 %
SUV	1,823	1,931	3,754	259	41 %
Van	167	239	406	14	2 %
Total	5,429	6,218	11,647	627	100 %

Source: State Data System

Table 10. Vehicles involved in fatal crashes with a rollover occurrence

Vehicle Type	2011		2012		2011 + 2012	
	Vehicles Involved in Fatal Crashes	Rollover Occurrence	Vehicles Involved in Fatal Crashes	Rollover Occurrence	Number of Rollovers	Proportion, by Vehicle Type
Passenger Car	17,508	2,680	18,269	2,827	5,507	38 %
Pickup	7,790	2,050	8,001	2,117	4,167	28 %
SUV	6,787	2,128	7,118	2,170	4,298	29 %
Van	2,187	365	2,173	316	681	5 %
Total	34,272	7,223	35,561	7,430	14,653	100 %

Source: FARS

The agency performed a logistic regression analysis of the 11,647 single-vehicle crash events. The dependent variable in this analysis is vehicle rollover, while the independent variables are SSF, light condition, driver age, driver gender, and the State indicator variable. The SAS® logistic regression program used these variables to compute the model. The SAS® statistical analysis software output tables are available in the docket for this RFC notice. Figure 4 shows a plot of the predicted rollover probability versus the SSF for the 20-State dataset. Figure 5 is a plot of the average predicted probability of rollover for each SSF in the dataset. Figures 4 and 5 demonstrate the relationship between SSF and the predicted probability of rollover, that at every level of SSF the predicted probability of rollover is less than it was estimated to be in 2003. The flatter curve for the 2011 + 2012 dataset aligns with increased vehicle SSFs, the

expected effect of ESC on rollover frequency, and the reduced observation of rollover in single-vehicle crashes.

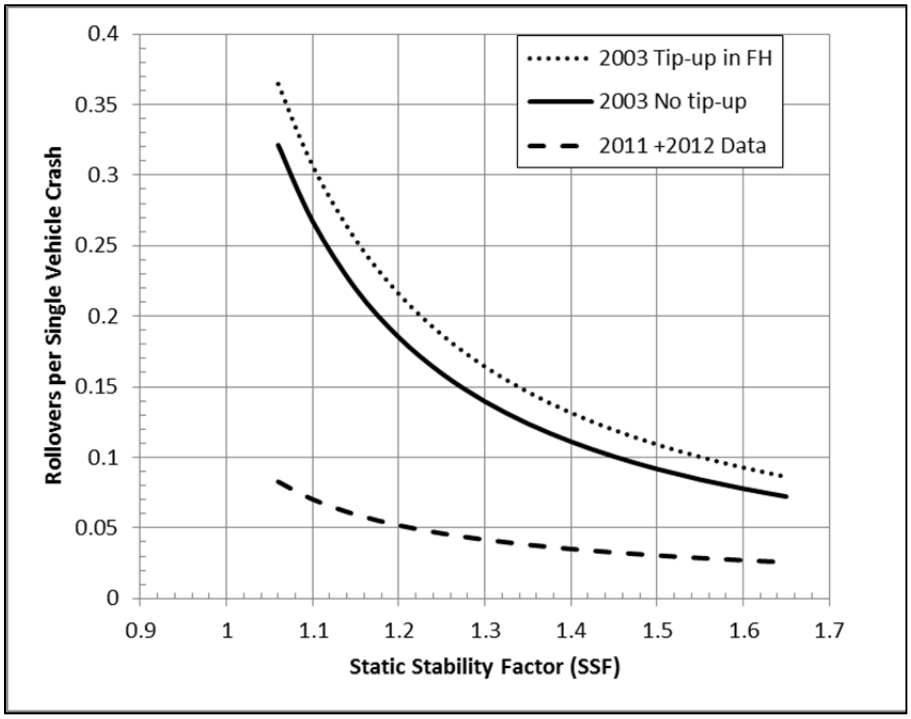

Figure 4. Current and new rollover risk curve

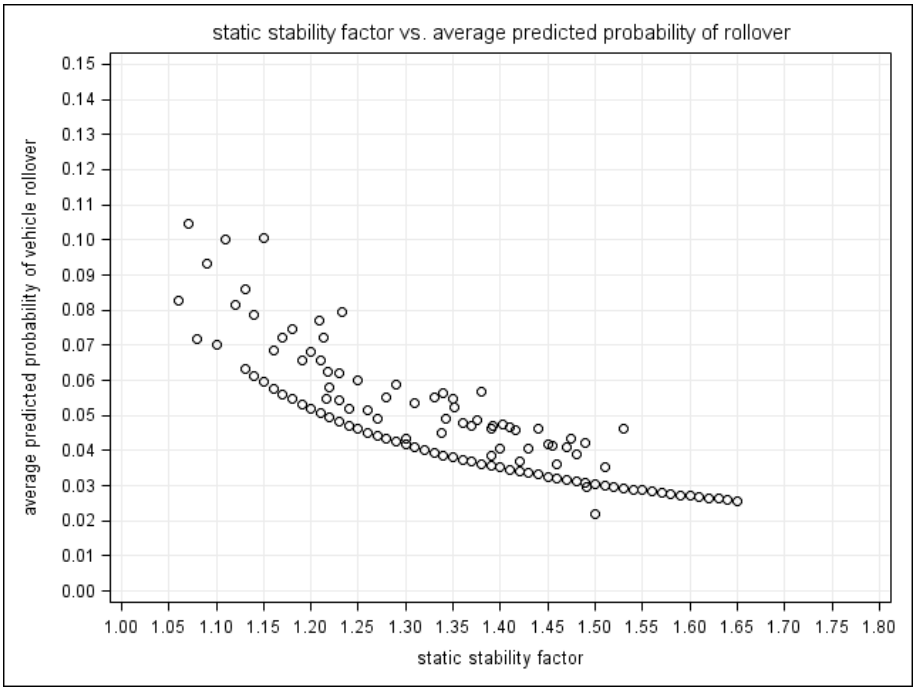

Figure 5. 2011 + 2012 average predicted rollover probabilities with the logistic regression curve

A statistical risk model is not currently possible for untripped rollover crashes because they are relatively rare events and they cannot be reliably identified in the State crash reports. The method applied earlier, using test track data, did not work, because vehicles do not routinely tip-up in testing. NHTSA intends to continue to use the current SSF-based approach to rate resistance to tripped rollovers in this NCAP upgrade. Field data collected over the past 10 years shows 95 to 97 percent of the rollovers are tripped. The agency has no data that suggests this will change.

The agency has worked for decades to reduce the number of rollovers and the resulting injuries and fatalities. Three safety standards related to rollover have been promulgated or amended. These are: FMVSS No. 126, "Electronic stability control," FMVSS No. 216, "Roof crush resistance," and FMVSS No. 226, "Ejection mitigation."[285] [286] [287]

Congress funded NHTSA's rollover NCAP program and directed the agency to enhance the program under section 12 of the Transportation Recall, Enhancement, Accountability and Documentation (TREAD) Act of November 2000.[288] In response to this mandate, NHTSA created a dynamic maneuver known as the Fishhook test, a double steering maneuver, conducted at speeds of up to 50 mph. The maneuver is performed with an automated steering controller, and the reverse steer of the Fishhook maneuver would be timed to coincide with the maximum roll angle to create an objective ''worst case'' for all vehicles regardless of differences in resonant roll frequency, which is the vehicle's natural roll response. This NCAP driving maneuver test

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[285] 72 FR 17236. Docket No. NHTSA-2007-27662. Available at https://federalregister.gov/a/07-1649.
[286] 74 FR 22348. Docket No. NHTSA-2009-0093. Available at https://federalregister.gov/a/E9-10431.
[287] 76 FR 3212. Docket No. NHTSA–2011–0004. Available at https://federalregister.gov/a/2011-547; corrected 76 FR 10524. Available at https://federalregister.gov/a/C1-2011-547.
[288] Public Law 106-414, November 1, 2000.

represents an on-road untripped rollover crash, which represents less than 5 percent of rollover crashes.

The rollover resistance test matrix consists of a static measurement and a dynamic maneuver test. NHTSA intends to continue to use the same two tests it is using to determine the current rollover resistance NCAP rating. First, the SSF is measured statically in a laboratory, using the VIMF. The movement of the table predicts the height of the center of gravity. The track width of the vehicle is measured, and the SSF is accurately calculated. NHTSA believes that including the average SSF in the NCAP crash avoidance rating, and making the SSF available to consumers would lead to an improved fleet average SSF. Analysis of the first 10 years of NCAP make-model data shows the average SSF for SUVs improved from 1.17 to 1.21.[289] This correlates to an average reduction in the risk of rollover in a single-vehicle crash for SUVs of 11.8 percent. Similarly for passenger cars, the average SSF remained the same at 1.41. With a c.g. lower than SUVs, passenger cars have better SSFs. The second test uses the Fishhook test on a large test area, attempting to tip up the vehicle. These two tests combined provide the risk of rollover, and the current Monroney safety label rollover resistance star rating.[290] Vehicles with a higher c.g., such as an SUV, van or pickup truck typically have a higher rollover propensity than a passenger car with a lower c.g.

Initially, five levels of risk were defined based on dividing the linear regression curve into 5 bands, representing the 1- through 5-star bands, similar to the rating system for the current NCAP crashworthiness ratings. The 1-star rating corresponds to a risk of greater than 40-percent chance of rollover in a single-vehicle crash. The 5-star rating represents a less than 10-percent

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[289] NHTSA internal research analysis.
[290] The Monroney label on each new vehicle offered for sale in the United States displays a safety star rating for expected rollover performance based on the predicted rollover rate.

risk of rollover in a single-vehicle crash. Currently, the predicted rollover rate translates to an NCAP star rating such that 1 star is awarded for a rollover rate greater than 40 percent; 2 stars, greater than 30 percent and less than 40 percent; 3 stars, greater than 20 percent and less than 30 percent; 4 stars, greater than 10 percent and less than 20 percent; 5 stars, less than or equal to 10 percent. This approach achieved NHTSA's goal of presenting risk-based ratings. With a flatter rollover risk curve, defining the star bands is less obvious and more challenging. As expected, vehicles equipped with ESC have a much smaller predicted rollover probability, including vehicles with low SSFs. The range of the average predicted probability of vehicle rollover for ESC-equipped vehicles is significantly smaller than the current range. The agency intends to shift the star bands for a rollover risk curve of ESC-equipped vehicles such that 1 star would be awarded for a rollover rate greater than 0.08 percent (or SSF $\leq$ 1.07); stars, greater than 0.06 percent and less than 0.08 percent (or 1.07 < SSF $\leq$ 1.15); 3 stars, greater than 0.04 percent and less than 0.06 percent (or 1.15 < SSF $\leq$ 1.32); 4 stars, greater than 0.030 percent and less than 0.04 percent (or 1.32 < SSF $\leq$ 1.50); 5 stars, less than 0.030 (or SSF > 1.50). Comments are requested on these adjusted rollover star bands.

In this upgrade of NCAP crash avoidance rating, NHTSA intends to calculate the contribution of rollover resistance as a proportion of the maximum number of points awarded for rollover resistance. The credit for rollover resistance would be the number of stars earned based on the SSF divided by five, and then multiplied by the rollover resistance rating point value.

c. Blind Spot Detection (BSD)

NHTSA intends to include BSD in its crash avoidance rating for this NCAP upgrade. BSD systems use digital camera imaging technology or radar sensor technology to detect one or more vehicles in either of the adjacent lanes that may not be apparent to the driver. The system

warns the driver of an approaching vehicle's presence to help facilitate safe lane changes. If the blind spot warnings are ignored, some systems include enhanced capability to intervene by applying brakes or adjusting steering to guide the vehicle back into the unobstructed lane. However, NHTSA does not plan to rate the system's capability to initiate automatic avoidance maneuvers in its NCAP rating at this time.

The BSD system processes the sensor information and presents visual, audible, and/or haptic warnings to the driver. A visual alert is usually an indicator in the side mirror glass, inside edge of the mirror housing, or on the A-pillar inside the car. If enabled, the manner in which the light is illuminated often depends on the driving situation. When another vehicle is present in an adjacent lane, and within the driver's blind spot, systems will typically illuminate the warning light continuously. When the driver activates the turn signal in the direction of the adjacent vehicle, the warning light will often flash. Some systems will also present an audible or haptic alert coincident with the flashing light.

As stated in NHTSA's "Vehicle Safety and Fuel Economy Rulemaking and Research Priority Plan, 2011 to 2013," the agency examined the potential of sensors and mirrors to detect vehicles in blind spots to assist in lane changing maneuvers.[291] Using data from GES during the period 2003-2007, a target population for which blind spot detection technology would apply is estimated to be an average of 96,100 crashes annually, resulting in approximately 4,700 injuries per year and 146 fatalities per year.[292]

Anecdotal evidence from IIHS and AAA indicates that BSD systems have the potential to provide safety benefits and appear to be most effective when the equipped vehicle is passing,

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[291] www.nhtsa.gov/staticfiles/rulemaking/pdf/2011-2013_Vehicle_Safety-Fuel_Economy_Rulemaking-Research_Priority_Plan.pdf.
[292] NHTSA internal research analysis.

being passed, or preparing to make a lane change.[293] Lane change maneuvers may be planned or unplanned by drivers, and they may or may not involve use of the turn signal. Market research indicates that BSD systems consistently rate high or desirable in consumer interest surveys among various safety systems.[294] However, reduced crash rates are not easily isolated to blind spot detection technology specifically.

A May 2010 study funded by IIHS estimated that outside rearview mirror assist systems could prevent 395,000 vehicle crashes annually, potentially avoiding 20,000 injuries and 393 fatalities.[295] IIHS determined that 2011 crash data suggests 350,000 single- and two-vehicle crashes involved vehicles merging or changing lanes, which resulted in 665 fatal crashes and 59,000 injury causing crashes. The Bosch crash causation study, based on 2011 data from the NHTSA NASS database, indicated that five percent of all collisions with injuries and fatalities occurred between vehicles travelling in the same direction.[296] Bosch concluded that a significant portion of these collisions are attributable to drivers not being aware of other vehicles in their vicinity at the time of a lane change maneuver. Bosch determined that this accounted for over 77,000 collisions per year in the United States.

NHTSA research suggests the benefits of BSD systems may be smaller than the industry studies cited; however, consensus is building that drivers may benefit from BSD systems that offer the potential to reduce crash rates, and by extension, reduce injuries and fatalities in lane change related crash scenarios. NHTSA used simulation to estimate blind spot detection effectiveness for a generic sensor and found it to be between 42 percent and 65 percent,

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[293] AAA Automotive Engineering, Evaluation of Blind Spot Monitoring and Blind Spot Intervention Technologies, 2014.
[294] DOT HS 811 516, Integrated Vehicle-Based Safety Systems (IVBSS) Light Vehicle Field Operational Test Independent Evaluation, October 2011; and J.D. Power's 2015 Tech Choice Study.
[295] IIHS Status Report, Vol. 45, No. 5, May 20, 2010.
[296] Comment submitted by Robert Bosch, LLC, at www.regulations.gov, Docket No. NHTSA-2012-0180-0028.

indicating prevention of 40,000 to 62,000 crashes, 2,000 to 3,000 injuries, and 61 to 95 fatalities.[297]

AAA reported that BSD systems they tested worked well, however, they cautioned that these systems are not a substitute for an engaged driver and BSD system performance can vary greatly. The agency recognizes that differences in the detection capabilities and operating conditions will likely exist among the currently available BSD systems. For instance, one manufacturer may describe their system's capabilities as demonstrating designed performance for higher speed lane change events, whereas another manufacturer may emphasize its system's augmentation of the driver's visual awareness rather than a level of effectiveness for preventing crashes. The agency anticipates a wide range of NCAP test results initially, due in part to the competing OEM perspectives as well as the establishment of performance criteria in this RFC notice.

The agency intends to use the draft BSD test procedure included in Appendix VIII to assess vehicles for this NCAP upgrade. The agency seeks comment on these procedures. Each NCAP vehicle equipped with a BSD system would be subjected to three performance tests to determine whether the system displays the warning when other vehicles are in a driver's blind zone, independent of activation of the vehicle's turn signal. Because weather and environmental conditions (e.g., snow, rain, and fog) can disrupt radar signals and digital camera images, the NCAP tests would be conducted under dry conditions with the ambient temperatures above 32º F (0º C) and below 90º F (32º C). Similarly, the NCAP test conditions would minimize shadows and sunlight at sunrise and sunset in an effort to reduce false-positive alerts. The NCAP blind spot detection tests are designed to detect vehicles only, not motorcycles, pedalcycles, humans,

[297] NHTSA internal research simulation.

or animals. Comments are requested on whether the NCAP test should include detection of motorcycles.

NCAP would test vehicles equipped with BSD systems under three driving scenarios; straight-lane, POV pass-by, POV and Secondary Other Vehicle (SOV) pass-by. The POV and SOV configurations would be mid-size sedans. The straight-lane scenario is very relevant to blind spot detection testing as it is the scenario that is most likely to be encountered in every day driving.[298] In the straight-lane test, both the SV and POV are driven in separate but parallel lanes with the POV driven longitudinally past the SV. In every NCAP blind spot detection test, the SV would be driven at a constant speed of 45 mph. For the straight-lane scenario, the POV would be driven at increased speeds of 5, 10 and 15 mph above the SV, as well as at the same speed to test for false-positives. This test mirrors the ISO 17387 standard test.

The second scenario, the POV pass-by scenario, is another scenario likely to be encountered in every day driving situations for vehicles travelling at highway speeds. The objective of the POV pass-by test is to determine if the system identifies a POV making a combined lane change and pass-by. The third scenario, the POV and SOV pass-by scenario, is similar to the straight-lane scenario but with the use of a third vehicle. The objective of the POV and SOV pass-by test is to determine if both the left and the right blind spot detection sensors activate simultaneously and to determine if there is any interaction when activating a turn signal on only one side of the SV while both sensors may be indicating alerts.

Each BSD system test would be performed once, unless there are any invalid test parameters or a failure then the test would be repeated. Two consecutive failures results in a

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[298] DOT HS 812 045, July 2014. Available at www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2014/812045_Blind-Spot-Monitoring-in-Light-Vehicles-System-Performance.pdf

BSD system fail. The left and right sides of the SV would be tested for the straight-lane and POV pass-by scenarios, with the SV turn signal activated for one trial and off for the other trial. The BSD system must detect the POV in both trials. For the POV and SOV pass-by scenario, the SV turn signals would not be activated.

4. Future Technologies

Several advanced technologies that are good candidates for this consumer information program are in various stages of development but are not ready at this time. For example, intersection movement assist (IMA), lane keeping support (LKS) systems, automatic collision notification (ACN)/ advanced automatic collision notification (AACN) systems, distraction guidelines, and driver alcohol detection system for safety (DADSS). These technologies are briefly described below. NHTSA is researching these technologies and requests comment on them to aid this research.

IMA is a prototype crash avoidance technology that relies on vehicle-to-vehicle (V2V) communications. Rather than relying on sensors, radar, or cameras, IMA uses on-board dedicated short-range radio communication devices to transmit messages about a vehicle's speed, heading, brake status, and other information to other vehicles capable of receiving those messages and translating them into alerts and warnings, which the driver can then respond to in order to avoid a crash. Current IMA prototype designs may be able to warn drivers about 5 types of junction-crossing crashes which collectively represent 26 percent of all crashes occurring in the crash population and 23 percent of comprehensive costs.[299]

[299] DOT HS 812 014, August 2014. Available at www.nhtsa.gov/staticfiles/rulemaking/pdf/V2V/Readiness-of-V2V-Technology-for-Application-812014.pdf.

LKS systems are extensions of the current lane departure warning systems that actively guide the vehicle within the lane. LKS, also known as lane centering, gently provides corrective guidance of the vehicle, without overpowering the driver's control of the vehicle.

AACN systems notify a public safety answering point (9-1-1), either directly or through a third party, of a crash when that crash reaches a minimum severity (e.g., air bag deployment). In addition to providing response personnel an earlier notification of the crash, the AACN system will transmit information regarding the location of the crash. These systems also have the capability to predict the severity of the crash and can indicate when there is a high probability of severe injury. This injury severity prediction could be used by emergency personnel to change how they respond to a crash and what type of hospital to take the patient to (e.g., community hospital versus level I trauma center).

In April 2010, NHTSA released an overview of the agency's Driver Distraction Program,[300] which summarized steps that the agency intends to take to help in its long-term goal of eliminating a specific category of crashes attributable to driver distraction. Phase 1 of the NHTSA Driver Distraction Guidelines was developed for original equipment in-vehicle interfaces that allow the driver to perform secondary tasks through visual-manual means.[301] The Guidelines specify criteria and a test method for assessing whether a secondary task performed using an in-vehicle device may be acceptable in terms of the distraction performance metrics while driving. The Guidelines identify secondary tasks that interfere excessively with a driver's ability to safely control their vehicle and to categorize those tasks as ones that are not acceptable

[300] See www.regulations.gov, Docket No. NHTSA-2010-0053-0001.
[301] See 78 FR 24818, Docket No. NHTSA-2010-0053-0135. Available at https://federalregister.gov/a/2013-09883.

for performance by the driver while driving. Phases 2 and 3 of the Driver Distraction Guidelines are under development.

The DADSS program is a collaborative research partnership between industry and NHTSA to assess and develop alcohol-detection technologies to prevent vehicles from being operated by drivers with a blood alcohol concentration (BAC) that exceeds the legal limit as set by the State. Through the DADSS research program, the agency intends to explore the feasibility of, the potential benefits of, and the potential challenges associated with a more widespread use of in-vehicle technology to prevent alcohol-impaired driving.

E. Pedestrian Crash Avoidance Systems

New vehicle technologies are shifting the automotive safety culture from a dual focus of helping drivers avoid crashes and protecting vehicle occupants from the inevitable crashes that would occur to a triple focused approach with the addition of advanced systems that enable protecting pedestrians. Accordingly, the agency intends to increase its focus on advanced technologies that aim to protect not just vehicle occupants but pedestrians. Two crash avoidance technologies that the agency intends to include in this NCAP upgrade and rate their system performance in the pedestrian protection rating category are discussed below. NHTSA requests comment on these systems, and their readiness for inclusion in NCAP.

1. Pedestrian Automatic Emergency Braking (PAEB)

NHTSA is researching systems that will automatically brake for pedestrians, in addition to automatically braking for vehicles. PAEB would provide automatic braking for vehicles when pedestrians are in the forward path of travel and the driver has taken insufficient action to avoid an imminent crash. Table 6 shows PAEB systems map to two of the 32 crash scenarios.

PAEB, like CIB, is a vehicle crash avoidance system that uses information from forward-looking sensors to automatically apply or supplement the brakes in certain driving situations in which the system determines a pedestrian is in imminent danger of being hit by the vehicle. Many PAEB systems use the same sensors and technologies used by CIB and DBS; systems designed to help drivers avoid or mitigate the severity of rear-impact crashes with other vehicles. Like AEB technology, current PAEB systems typically use vision-cameras as the enabling sensor technology, however some systems also use a combination of cameras and radar sensors.

Unlike CIB and DBS, which address rear-impact crash scenarios, many pedestrian crashes occur when a pedestrian is crossing the street in front of the vehicle. In these pedestrian crash scenarios, there may not be enough time to provide the driver with an advanced FCW alert before the PAEB system must automatically apply the brakes.

NHTSA has conducted research in this area and intends to include PAEB in this NCAP upgrade. Pedestrians are one of the few groups of road users to experience an increase (8%) in fatalities in the United States in 2012, totaling 4,818 deaths that year.[302] Of these deaths, 3,930 fatalities occurred in frontal crashes (as stated earlier).

For AEB systems, detecting a pedestrian and preventing an impact is more complex than detecting a vehicle. Pedestrians move in all directions, change directions quickly, wear a variety of clothing materials with colors that may blend into the background, are a wide variety of sizes, and may be in an array of positions, from stationary to lying on the road. Pedestrians' appearances can appear to be more variable than cars to AEB systems. Additionally, the time to collision from when a system first detects a pedestrian might be shorter than for a car because

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[302] National Highway Traffic Safety Administration (2015). Traffic Safety Facts – Pedestrians (DOT HS 812 124). Available at www-nrd.nhtsa.dot.gov/Pubs/812124.pdf

they are moving at slow speeds, may be crossing the road in front of the car, they are much smaller than a vehicle, and they may be obscured by cars parked on the side of the road. NHTSA crash data indicates pedestrians may be anywhere on the roadway, at all times of the day and night, moving in every possible direction; sometimes crossing interstate roadways to take short-cuts and at other times simply crossing in a crosswalk.

NHTSA has completed a substantial amount of research into PAEB and has collaborated with Volpe, the National Transportation Systems Center. NHTSA is currently working on research that could eventually support the inclusion of PAEB into NCAP. This effort includes the assessment of mannequins (pose-able and/or articulated), PAEB testing apparatuses and PAEB test procedures. Volpe is currently working on a new safety benefit analysis for PAEB systems that will include new estimates for the benefits of PAEB in combination with different safety systems.

A recent analysis of the physical settings for pre-crash scenarios and vehicle-pedestrian maneuvers identified trends for these pedestrian crashes. Four scenarios were identified as the most commonly occurring situations during pedestrian crashes and are recommended to maximize the potential safety benefits of PAEB systems.[303]

The four scenarios are (S1) vehicle going straight and pedestrian crossing the road, (S2) vehicle turning right and pedestrian crossing the road, (S3) vehicle turning left and pedestrian crossing the road, and (S4) vehicle going straight and pedestrian walking along/against traffic. These 4 scenarios addressed 67 percent of the 20 most frequent conditions involved with intersections, pedestrian location, crosswalks, and road geometry during 2005 to 2009. Of these

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[303] Barickman and Albrecht, SAE Government Industry Meeting, 2015, "Pedestrian Crash Avoidance Research Program Update."

four scenarios, S1 represents 88 percent of the occurrences of the top 20 pedestrian fatality scenarios. These 4 recommended scenarios encompassed 98 percent of all functional years lost and direct economic cost of all vehicle-pedestrian crashes in 2005 to 2009.

S1 is the most frequent pre-crash scenario and therefore has the highest values for the functional years lost and direct economic cost measures. S2 and S3 address the common turning scenarios observed in the crash data. Although S2 and S3 scenarios result in less severe injuries, NHTSA believes PAEB systems include these scenarios to function effectively. The agency requests comment on current PAEB system functionality in turning situations, as well as system capabilities in the future. Scenario S4, pedestrian walking along/against traffic, has the second highest fatality rate, and would require PAEB systems to have high-accuracy pedestrian detection at high travel speeds to address these scenarios.

The typical methods for avoiding a crash are to slow down or stop. A driver may attempt to steer the vehicle around a pedestrian in some cases. However, the pedestrian may also be attempting to flee the line of travel of the vehicle, so steering may create a more hazardous situation. Braking is the preferred action for avoiding striking a pedestrian or reducing the possible injury to the pedestrian. (Steering to avoid the pedestrian may cause another type accident or even steer toward the moving pedestrian.) Even if the collision is not avoided, the vehicle speed may be significantly reduced and the pedestrian's injuries may not be as severe as would have occurred without braking, particularly with the pedestrian crashworthiness changes to NCAP as discussed in section V.C of this RFC notice. NHTSA believes the best automatic system characteristic would be to automatically apply the brakes in the event of an imminent collision.

For scenario S1, NHTSA has determined that PAEB systems may be effective at reducing 83 percent of the crashes involving walking pedestrians that received a MAIS 3+ injury/fatality. NHTSA data from 2009 suggests these safety benefits would be 317 severe injuries or fatalities avoided annually.[304]

To date, the agency is still refining the pedestrian test scenarios. With the help of the industry/government collaborative effort known as Crash Avoidance Metrics Partnership (CAMP), NHTSA has made significant progress in developing the PAEB performance tests. The potential test procedure includes a pedestrian in a straight roadway and the subject vehicle moving in a straight path. The potential test scenarios captured by this procedure include walking across the road (S1), walking along the roadway (S4), two different vehicle speeds 10 and 25 mph (16 and 40 km/h), three different mannequin speeds (stationary, walking, running), two different sized mannequins (child, adult), and false activations (e.g., curves, hillcrests, light conditions, erratic pedestrian movement).

NHTSA has used light-weight adult and child pedestrian dummies. These dummies are both somewhat realistic looking and have radar reflective properties.

In developing the test procedure, three general apparatus concepts were identified for transporting the pedestrian mannequins in a test run. These included two overhead, gantry-style designs and one moving sled arrangement. Several adaptations of each concept were also considered. The overhead suspended truss was selected by CAMP to conduct baseline and validation research. NHTSA is using a ground-based moving sled arrangement for current PAEB research.

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[304] DOT HS 811 998, "Target Crashes and Safety Benefits Estimation Methodology for Pedestrian Crash Avoidance/Mitigation Systems," April 2014.

It should be noted that testing in the PAEB program assumes considerable speed reduction (crash mitigation) or in some cases complete avoidance maneuver by the production vehicle to accomplish pedestrian protection. Some PAEB systems have shown avoidance capabilities at the vehicle test speeds that are being considered. The intent of the performance tests is to establish realistic scenarios and to measure vehicle PAEB performance.

2. Rear Automatic Braking

NHTSA has funded studies of motor vehicle advanced technologies that will help drivers avoid pedestrian impacts. Recently, the agency established a FMVSS requiring rearview video systems in passenger vehicles, providing a view of a 10-foot wide by 20-foot long area behind the vehicle. The agency intends to include rear automatic braking systems in this NCAP upgrade, which is separate from and in addition to the requirements specified in FMVSS No. 111, "Rear visibility," for light vehicles manufactured on or after May 1, 2018, to provide the driver with a rearview image.

NHTSA expects rear visibility systems to have a substantial impact on the over 200 pedestrians killed each year resulting from backover crashes. Rear visibility systems meeting the minimum performance standards of FMVSS No. 111 rely on the driver to view the rearview image and then act appropriately to avoid a pedestrian crash. The agency expects that 58 to 69 lives will be saved by rear visibility systems each year when fully implemented. However, rear visibility systems will not completely solve the backover crash problem; 141 to 152 lives are expected to be lost each year in backover crashes, even with rear visibility systems on all new light vehicles. As shown in Table 6, rear automatic braking could potentially prevent or mitigate a crash in 7 of the 32 crash scenarios listed.

For NCAP purposes, a rear automatic braking system is defined as a system that applies the vehicle's brakes, independent of driver action, in response to the presence of an object in a specified area behind the vehicle during backing. For NCAP, NHTSA's test procedure would assess the rear automatic braking systems' ability to detect pedestrians and brake the vehicle to a stop to avoid a crash. While avoiding slow moving or stationary objects such as poles and parked vehicles may provide economic benefits for drivers, NHTSA is focusing on reducing fatalities and injuries, and therefore on system performance to avoid crashes with pedestrians.

Information pertaining to the ability of a rear automatic braking system to aid in avoiding pedestrian crashes may be difficult for an individual consumer to obtain in a uniform way that can be easily understood and compared across manufacturers. The NCAP program would serve as a trusted source for consumers for pedestrian crash avoidance information.

Accompanying this RFC notice, the agency is publishing a draft test procedure that evaluates rear automatic braking systems. Including this assessment in NCAP would encourage manufacturers to add technology that would automatically detect and avoid rearward pedestrian crashes. NHTSA intends to use the test procedure identified in Appendix VIII and contained in the docket to assess the ability of a rear automatic braking system to avoid striking pedestrians behind the vehicle by using a static surrogate child pedestrian ATD. The posable mannequin is tuned for RADAR, infrared, and optical features. NHTSA expects the technology (explained in more detail below), now focused on large objects approaching a backing vehicle, will evolve to the point where it will effectively and reliably detect pedestrians, warn drivers and, if appropriate, apply the brakes automatically to stop the vehicle.

For the 2014 model year, NHTSA is aware of only two vehicle makes and models that offered rearward collision avoidance systems, both of which were described as not able to detect

every object. This advanced safety feature was available on both vehicles as options. NHTSA purchased two 2014 model year vehicles equipped with rear automatic braking systems for testing. One manufacturer's literature explained that their "Automatic Front and Rear Braking" will apply emergency braking automatically in certain driveway, parking lot and heavy traffic conditions if it detects a vehicle in front of or behind the subject vehicle. Additionally, it was noted that under many conditions these systems will not detect children, pedestrians, bicyclists, or animals. Similarly, the second vehicle owner's manual explained that the radar sensors of their "Back-up Collision Intervention" system detect approaching (moving) vehicles. Neither owner's manual characterized the rearward detection and collision avoidance system as being able to detect pedestrians. Both systems were described as automatically applying vehicle brakes in certain circumstances.

The sensor technologies used in automatic braking systems are known to have the ability to detect pedestrians, to some extent. Using the two 2014 makes and models with rearward collision avoidance systems, NHTSA conducted its own experimental testing to determine how well the systems respond to pedestrians and other test objects (e.g., cone, pole, surrogate vehicle, ride-on toy). In the test, the subject vehicle was allowed to coast backward while maintaining centerline alignment with a longitudinal line marked on the ground until the rear automatic braking feature intervened by automatically engaging the service brakes bringing the vehicle to a stop or until the vehicle contacted the test object. The initial test results indicate that detection performance is not consistent across all test objects. When the NHTSA test report is published, a copy will be entered into the docket. The results of this experimental testing served as the basis for the draft test procedure that is included in Appendix VIII and on which the agency seeks comment.

Similar to the forward AEB systems, the metrics for rear automatic braking system tests would be a pass-fail criterion. If all the tests are passed, the vehicle would get credit for having the technology. This would be calculated in the pedestrian rating calculation. If a rear automatic braking technology is offered as an optional safety technology, the vehicle model would receive half credit for this technology. If a rear automatic braking technology is a standard safety technology, the vehicle model would receive full credit for this technology.

VI. New Rating System

A. Overall Rating

NHTSA is planning to change the way NCAP rates vehicles for safety. An effective rating system: (a) provides consumers with easy-to-understand information about vehicle safety, (b) provides meaningful comparative information about the safety of vehicles, and (c) provides incentive for the design of safer vehicles. As such, NHTSA believes an effective rating program will discriminate truly good performance in safety and spur continuous vehicle safety improvement.

The current NCAP rating system comprises an overall rating score (also known as Vehicle Safety Score or Overall Vehicle Score), which is computed as the field-weighted scores from the full frontal crash, side crash (side MDB and side pole), and rollover resistance tests. It is based on a 5-star rating scale that ranges from 1 to 5 stars, with 5 stars being the highest. The overall rating score does not include assessment of existing advanced crash avoidance technologies recommended under the NCAP program, which are listed as Recommended Technologies on the agency's Safercar.gov website.

This NCAP upgrade described in this RFC notice would provide an overall star rating and individual star ratings for crashworthiness, crash avoidance, and pedestrian protection

categories. Past market research conducted by NHTSA reveal that consumers prefer a simplified rating and process. Therefore, NHTSA intends to ensure the revised star rating and process is simplified and easy to understand.

While star ratings would be maintained as a range from 1 to 5 stars, the agency is also planning to use half stars to allow better discrimination of safety so that consumers can make informed purchasing decisions. The planned approaches for determining the crashworthiness, crash avoidance, and pedestrian star ratings are described in the following sections.

NHTSA request comment on the general decision to only provide category rather than test-based star ratings, as well as comment on how to best combine the individual categories in an easy to understand manner. The agency is also interested in any other possible approaches not mentioned in this RFC notice.

B. Crashworthiness Rating

NHTSA intends to provide a single-star rating for the crashworthiness performance of new vehicles by evaluating a vehicle's performance in four crash test modes (full frontal rigid barrier, frontal oblique, side MDB, and side pole). Depending upon the test, one to three crash test dummies will be used for assessment. Each dummy has numerous body regions for which criteria to assess the risk of injury will be evaluated.

The following describes how NHTSA could use the results from various crash test modes in calculating a vehicle's crashworthiness star rating. The agency is seeking comment on the following approaches and other alternatives.

Assessing injury criteria

The agency is considering the following approaches for assessing injury criteria in the dummies used in the crash tests.

- Based on calculated injury risk – Use injury risk functions for each body region that has an injury risk function available and that is applicable to the dummy involved.
- Based on a fixed range of performance criteria – A set of performance criteria can be implemented using injury risk curves, existing Federal regulations, other agency data, or a combination thereof. One possible implementation of this approach could be similar to the Euro NCAP approach, where lower and upper performance targets would be set for each body region assessed, and a point system would be used for the given occupant. Full points would be awarded for achieving the upper target or better, a linearized number of points would be awarded for performance between the lower and upper targets, and no points would be awarded for the given occupant if the lower performance target is not met.
- Based on current fleet performance – Similar to current NCAP, injury assessment could be determined based on relative fleet performance in NCAP tests. One possible implementation of this approach would result in the best-performing vehicle receiving the highest score and the worst-performing vehicle receiving the lowest score.

Combining each injury criteria for an occupant seating location score

For combining the injury criteria from several body regions into a combined injury risk or score for each occupant seating location, the following approaches are under consideration:

- Equal weighting for all body regions – Weight all body regions equally and calculate a joint probability of injury (or joint score) for a given occupant based on all available

injury criteria or body regions. This essentially reflects the approach currently used in NCAP.

- Weighting using field data – Injury criteria for the body regions could be weighted based on the incidence, cost, mortality, or severity of injury, and then combined into a joint probability (or joint score) for that occupant seating position.
- Partial weighting using field data, subject to constraints – Injury criteria for body regions that have a low incidence of injury for a given occupant seating location would alternatively be evaluated using a constraint method with an established threshold. For example, for a given occupant, body regions of higher significance could be assessed through a joint probability of injury approach, and body regions of less significance could be assessed using a constraint method whereby a minimum performance must be met. A possible implementation of the constraint method could be, for example, if the measured risk of injury exceeds a predetermined threshold, the score for the given occupant seating location would not be fully awarded. Instead, it would be capped at a certain level.

Combining each occupant seating location score into a test mode score and into a total crashworthiness rating

There are also several approaches to combining the score of each occupant seating location into a single combined score for each test mode or for the overall crashworthiness rating:

- Equal weighting for all occupants – Each dummy seating location would be weighted equally and the injury risks would be combined into a single test mode score. This approach could be carried out using a combined probability, a sum, or an average. This is essentially the approach used currently for the frontal NCAP assessment.

- Weighting using field data – The injury risk for each dummy location would be weighted based on the incidence, risk, occupancy, or other field-relevant data and then combined into a single test mode score.
- Partial weighting using field data, subject to constraints – Partial weighting using field data can be used for seating positions in a given crash mode that exceed a threshold criterion, such as percent occupancy or percent of overall fatalities. For those below a threshold value, a constraint system can be implemented whereby a minimum performance must be met before a given score is awarded in either the test mode or the total crashworthiness rating.

NHTSA seeks comment on these various approaches as well as other potential approaches not mentioned in this RFC notice.

C. Crash Avoidance Rating

As mentioned above, the agency intends to establish a new rating system for crash avoidance and advanced technology systems. To continue the accepted method of consumer information, a 5-star safety rating is preferred. Upon adoption of the planned rating, NHTSA intends to discontinue its practice of recommending advanced technologies on S*afercar.gov*. The agency may begin listing technologies that are available but that have not achieved the NCAP level of performance in the Safety Features box on the second page of each vehicle rating on *Safercar.gov*. All recent vehicle models that have a rearview video system are listed in this box, even if they do not achieve all of the performance in the NCAP test procedure. Currently, the agency intends to include 11 crash avoidance and advanced technology systems as part of the new rating system for the NCAP upgrade; 9 technologies in the crash avoidance rating described in this section and 2 crash avoidance technologies in the pedestrian rating that is described in the

next section. NHTSA selected these systems for inclusion in NCAP based on potential safety benefits.

The rating methodology for the crash avoidance and advanced technology systems under consideration would be based on a point system. For each technology, a point value for full or half credit would be determined. The maximum point value of all technologies earning full credit would equal 100 points. The point value of each individual technology, (designated A or B, etc. below) is based on the proportion of their individual benefit potential divided by the sum of all the benefits estimated for all of the technologies in the crash avoidance program projected onto a 100-point scale.

$$\frac{Benefit\ A}{Sum\ (Benefit\ A, Benefit\ B, etc)} X\ 100\ = Point\ value\ A \qquad \text{(Equation 1)}$$

Each technology then has its own total credit value toward the possible 100-point maximum score system. For technologies with pass or fail criterion, the credit may be awarded as total credit for pass performance or as no credit for fail performance. For example, a vehicle having a forward collision warning system might earn a 12-point credit toward the 100-point maximum score if it is standard equipment on that vehicle with acceptable performance.

Credit may be adjusted to a lesser value for several reasons. One reason would be in order to rate the performance of a particular technology into stratified levels of performance. For example, rating CIB by the amount of speed reduction can be divided into 5 levels of performance. A second example is the rollover rating. The rollover rating, currently a 5-star system, is based on the vehicle's static stability factor (SSF) and whether it tipped up in a dynamic test. The credit for rollover would be adjusted by 1/5th for each star earned with SSF. Equation 2 below is an example of how an adjusted credit would be calculated for rollover.

$$(Point\ value\ for\ rollover) * \left(\#\ of Stars * \frac{1}{5}\right) = Adjusted\ credit \qquad \text{(Equation 2)}$$

A second reason for adjusting the credit would be if the system is offered as optional equipment. Differentiation is introduced such that the vehicle would receive half credit for a technology that was offered as optional equipment with a take rate (i.e., options exercised by the consumer) above a pre-determined level and full credit for a technology that was standard equipment.

The overall score is than the sum of all the credits for all technologies.

$$\sum(Credit\ A, Credit\ B, etc.) = Overall\ Rating\ out\ of\ 100 \qquad \text{(Equation 3)}$$

The crash avoidance star rating scale may be a simple conversion of 1 star for every 20 credit points accumulated. A possible star-rating scale would be as follows in Table 11.

Table 11. Crash Avoidance Rating Scale

CA Point Total	CA Rating
1-19	1 star
20-39	2 star
40-59	3 star
60-79	4 star
80-100	5 star

As listed and shown in the table below, the crash avoidance systems would be separated into three categories with maximum points awarded to each technology:

- Category 1: Forward warning and AEB would include FCW (12 points), CIB (12 points), and DBS (11 points) – cumulative 35 points total.
- Category 2: Visibility would include lower beam headlighting (15 points), semi-automatic headlamp beam switching (9 points), and amber rear turn signal lamps (6 points) – cumulative 30 points total.
- Category 3: Driver Awareness/Other would include LDW (7 points), blind spot detection (8 points), and rollover resistance (20 points) – cumulative 35 points total.

Table 12. CA Technology Point Values

Crash Avoidance Technology	Point Value
Forward Warning and AEB	**35 total**
FCW	12
CIB	12
DBS	11
Visibility	**30 total**
Lower beam headlighting	15
Semi-automatic headlamp beam switching	9
Amber rear turn signal lamps	6
Driver Awareness/Other	**35 total**
LDW	7
Blind Spot Detection	8
Rollover Resistance	20

D. Pedestrian Protection Rating

NHTSA intends to rate vehicles for pedestrian protection using results from the four crashworthiness pedestrian tests (two headform, one upper legform, and one lower legform) and system performance tests of two advanced crash avoidance technologies that have the potential to avoid or mitigate crashes that involve a pedestrian and improve pedestrian safety – PAEB and rear automatic braking. From a consumer perspective, the agency believes that it is beneficial to aggregate the scores of PAEB and rear automatic braking systems with a vehicle's crashworthiness pedestrian protection scores so that a separate, single pedestrian protection score could be clearly distinguished from the other two ratings (crashworthiness and crash avoidance) for consumers. Consumers could then make informed purchasing decisions for their families about whether to purchase vehicles that are equipped with these pedestrian safety related features and technologies and rated in one category – pedestrian protection. Alternatively, the agency acknowledges that including these forward and rear automatic braking technologies in the crash avoidance rating calculation (instead of in the pedestrian protection rating calculation) may be an

effective means to encourage market penetration of these crash avoidance technologies. NHTSA seeks comment on the best approach to assess and rate a vehicle's various pedestrian protection performance features.

For the crashworthiness pedestrian score, NHTSA intends to use the same (or similar) scoring system and apportioning that Euro NCAP uses in accordance with the Assessment Protocol, "Pedestrian Protection, Part 1 – Pedestrian Impact Assessment, Version 8.1, June 2015." In short, the crashworthiness pedestrian safety scoring would be apportioned as follows:

- 2/3 of the score would be based on headform tests.
- 1/6 of the score would be based on upper legform tests.
- 1/6 of the score would be based on lower legform tests.

For the pedestrian crash avoidance score, the vehicle would receive credit for being equipped with the technology, provided that vehicle satisfies the performance requirements for each test scenario. If a PAEB or rear automatic braking system is offered as an optional safety technology, the vehicle model would receive half credit for the technology. If a PAEB or rear automatic braking system is offered as a standard safety technology, the vehicle model would receive full credit for the technology.

The agency requests comments on the approach to aggregate the four crashworthiness pedestrian test results with the two pedestrian crash avoidance test results into one pedestrian protection rating.

VII. Communications Efforts in Support of NCAP Enhancements

As NHTSA implements this NCAP upgrade planned for 2018 beginning with MY 2019 vehicles, communicating these changes to the public will be critical to ensure that consumers understand how the program will help them make informed choices about vehicle

safety and incentivize improvements in vehicle safety. NHTSA's efforts may include executing a comprehensive communications plan utilizing outreach strategies to inform and equip new vehicle shoppers with the latest vehicle safety information. The agency plans to publish a final decision notice in 2016, which will describe this NCAP upgrade in detail. The agency plans to begin its outreach efforts in the three years following that, prior to the planned program implementation in 2018. NHTSA is considering the following activities to effectively promote awareness of the changes in this NCAP upgrade and its new 5-Star Safety Ratings system:

- ***Consumer Information*** – As the vehicle research and purchasing process has largely shifted to online, so has the need to better convey vehicle safety information on *Safercar.gov*. Approaches to improving consumer information may include:
    - Enhancing topical areas under the 5-Star Safety Ratings and Safety Technologies sections on *Safercar.gov* – These areas may include providing more consumer-friendly information on NCAP's safety testing and criteria, results from individual crash test modes, as well as emerging vehicle safety technologies that are of significant interest to consumers.
    - Restructuring NCAP-related content on *Safercar.gov* to improve organization – Because the *Safercar.gov* site and its topics have grown, there is a need to reevaluate the landing page and reorganize some of the content so that consumers can more easily access safety information.
    - Improving the search functionality on the website – With the large amount of information in the NCAP database, more flexible search functionality is needed. NHTSA will look into improving the search function through the introduction of both advanced search programming and the introduction of new search features.

Common search feature requests to the agency include providing consumers with the option to search by crash avoidance technology or by star rating across vehicle class.

  - Creating engaging and interactive digital materials – In this digital age, consumers are more likely to watch video than read text-heavy content when learning about vehicle safety. NHTSA will explore creating digital materials that utilize videos (live-action, animated, or interactive) to educate consumers about the NCAP program.
  - Weaving simple, high-level messages into digital materials – Communicating this NCAP upgrade using clear, concise and consumer-friendly language is vital. Also, digital material that will be available on *Safercar.gov* will include consistent messaging.

- ***Dealer Toolkit*** – NHTSA intends to create tailored material describing important points about this NCAP upgrade to distribute to vehicle dealers. This material would help get dealers up-to-speed about the program enhancements so that they could communicate the changes to prospective vehicle purchasers. The material could include technical and tailored language required to effectively describe the new enhancements, including but not limited to the following:
  - Need for the new program;
  - Explanation of the key changes from the existing to the new program;
  - Benefits of the new program; and
  - List of the most anticipated questions from consumers.

In addition to material that educates dealers and dealer salesforces, NHTSA may also create material for distribution at the point of sale. For example, fact sheets or a 1-pager with frequently asked questions about NHTSA's new 5-Star Safety Ratings program could be on-hand so that prospective vehicle purchasers can learn how the program enhancements affect them and why it is important to make safety a priority in their vehicle purchases. This point-of-sale material could also include consistent branding and direct consumers to *Safercar.gov* where they can learn more about the program enhancements.

- ***Partner Outreach*** – Utilizing existing relationships and developing new partnerships with the online automotive community to better educate consumers and help distribute the messages to a broader audience would ensure that consumers are informed about the new program improvements. These third-party relationships would expand the agency's reach. NHTSA could work with existing third-party organizations and recruit additional partners to promote content on *Safercar.gov*. The agency believes that working with its partners will play a key role in the success of the launch of this NCAP upgrade. The agency is considering the following actions:
    - Develop collateral materials with partners to distribute through relevant channels;
    - Provide key messages and talking points about the new program enhancements to partners to distribute through their internal and external communications channels; and
    - Secure speaking opportunities with NHTSA officials at partner events to discuss the new program enhancements.
- ***Social Media*** – Messaging on NHTSA's social media platforms will also be important to inform consumers about the new program enhancements, by maintaining a steady

drumbeat of messages. NHTSA would monitor its social media channels and respond to online "conversations" in real-time, which would help increase engagement surrounding the new program improvements. NHTSA would also identify opportunities to re-tweet and re-post online influencers who interact with NHTSA's content. This would give users recognition for sharing NHTSA's content and also vary posts on the social media channel.

- ***Press Event*** – A series of media announcements from the U.S. Department of Transportation and NHTSA's officials about the new program would be made over the next few years to inform the public about this NCAP upgrade.

Once the agency considers the public comments and makes a final decision about what changes will be made to NCAP, it will address as appropriate, any applicable vehicle labeling issues relating to the Monroney label, commonly known as the vehicle window sticker.

VIII. Conclusion

Since its inception, NCAP has stimulated the development of safer vehicles. The agency recognizes the need to continually encourage improvements in the safety of vehicles by expanding the areas vehicle manufacturers need to consider in designing their vehicles and by making more challenging the tests and criteria on which NCAP star ratings are based. Only by doing this will NHTSA, and thereby consumers, be able to continue to identify vehicles with truly exceptional safety features and performance.

This RFC notice identifies a number of new areas the agency intends to add to NCAP as well as new assessment tools and tests. These include (1) adding a new frontal oblique crash test; (2) using a THOR 50th percentile male crash test dummy in the frontal oblique and full frontal tests; (3) replacing one of the dummies currently used in side crash testing with the WorldSID

50th percentile male dummy; (4) updating the rollover static stability factor risk curve to account for newer ESC-equipped vehicles that are less likely to be involved in rollover crashes; (5) adding crashworthiness pedestrian testing to measure the extent to which vehicles are designed to minimize injuries and fatalities to pedestrians struck by vehicles; (6) adding multiple new vehicle safety technologies to a group of advanced technologies already in NCAP; and (7) creating a new rating system that will account for all elements of NCAP – crashworthiness, crash avoidance, and pedestrian protection. Each of these areas has been discussed in detail above. As indicated earlier, the agency will be conducting additional technical work in some of these areas, the results of which will be made publicly available no later than the agency's release of the final decision notice.

The agency intends to issue a final decision notice regarding the new tools and approaches detailed in this RFC notice in 2016. NHTSA plans to implement these enhancements in NCAP in 2018, beginning with MY 2019 and later vehicles manufactured on or after January 1, 2018. Interested parties are strongly encouraged to submit thorough and detailed comments relating to each of the areas discussed in this RFC notice. Comments submitted will help to inform the agency's decisions in each of these areas as it continues to advance its NCAP program to encourage continuous safety improvements of new vehicles in the United States.

IX. Public Participation

How do I prepare and submit comments?

Your comments must be written and in English. To ensure that your comments are filed correctly in the docket, please include the docket number of this document in your comments.

Your comments must not be more than 15 pages long (49 CFR 553.21). NHTSA established this limit to encourage you to write your primary comments in a concise fashion.

However, you may attach necessary additional documents to your comments. There is no limit on the length of the attachments.

Please submit one copy (two copies if submitting by mail or hand delivery) of your comments, including the attachments, to the docket following the instructions given above under ADDRESSES. Please note, if you are submitting comments electronically as a PDF (Adobe) file, NHTSA asks that the documents submitted be scanned using an Optical Character Recognition (OCR) process, thus allowing the agency to search and copy certain portions of your submissions.

How do I submit confidential business information?

If you wish to submit any information under a claim of confidentiality, you should submit three copies of your complete submission, including the information you claim to be confidential business information, to the Office of the Chief Counsel, NHTSA, at the address given above under FOR FURTHER INFORMATION CONTACT. In addition, you may submit a copy (two copies if submitting by mail or hand delivery), from which you have deleted the claimed confidential business information, to the docket by one of the methods given above under ADDRESSES. When you send a comment containing information claimed to be confidential business information, you should include a cover letter setting forth the information specified in NHTSA's confidential business information regulation (49 CFR Part 512).

Will the agency consider late comments?

NHTSA will consider all comments received before the close of business on the comment closing date indicated above under DATES. To the extent possible, the agency will also consider comments received after that date.

Please note that even after the comment closing date, we will continue to file relevant information in the Docket as it becomes available. Accordingly, we recommend that interested people periodically check the Docket for new material.

You may read the comments received at the address given above under ADDRESSES. The hours of the docket are indicated above in the same location. You may also see the comments on the Internet, identified by the docket number at the heading of this notice, at *www.regulations.gov*.

Anyone is able to search the electronic form of all comments received into any of our dockets by the name of the individual submitting the comment (or signing the comment, if submitted on behalf of an association, business, labor union, etc.). You may review DOT's complete Privacy Act Statement in the Federal Register published on April 11, 2000 (65 FR 19477-78) or you may visit *www.dot.gov/privacy.html*.

X. Appendices

Appendix I: Frontal Crash Target Population

Recent NHTSA efforts have resulted in a more refined approach to analyzing frontal crash field data, from data sources such as the National Automotive Sampling System Crashworthiness Data System (NASS-CDS) and Crash Injury Research and Engineering Network (CIREN), than has been used in the past. The refined approach was developed to categorize frontal crashes more in terms of expected occupant kinematics during the crash event, as occupant motion and restraint engagement are more relevant to injury causation than the specifics of the vehicle damage (e.g., frontal plane crush). The new approach does not facilitate direct comparison with prior frontal crash target populations. The refined method is still based on vehicle damage characteristics such as Collision Deformation Classification (CDC) and vehicle crush measures,[305] but separates crashes into groups that are intended to be more indicative of occupant kinematic response. One feature of the new approach is the inclusion of some crashes that would previously have been considered side impact crashes due to the vehicle damage being on the side plane (based on the CDC area of deformation).[306] Those side impacts result in frontal-like occupant kinematics, and are more appropriately grouped into a frontal crash target population rather than a side impact target population when assessing frontal crash injury causation.

NASS-CDS data from case years 2000 through 2013 were chosen to establish the frontal crash target population. Passenger vehicles involved in tow-away non-rollover crashes were

[305] SAE J224 March 1980 Collision Deformation Classification.
[306] National Highway Traffic Safety Administration, "NASS Analysis in Support of NHTSA's Frontal Small Overlap Program," DOT HS 811 522, August 2011.

eligible for inclusion. The CDC of the most significant event was used to initially select frontal and frontal-oriented side impact crashes for analysis according to the following criteria:[307]

General Area of Damage (GAD1)	Specific Horizontal Location (SHL1)	Direction of Force (DOF1)
F	Any	Any
L	F,Y	11,12,1 o'clock
R	F,Y	11,12,1 o'clock

Elements of the CDC coding are described in SAE J224. The choice of which combinations of codes is determined by NHTSA. See DOT HS 811 522.

The Frontal Impact Taxonomy (FIT) uses the CDC, crush profile, principal direction of force (PDOF), and vehicle class-specific geometry indicators[308] to identify and classify frontal crash types within the broad set of crashes described above based on the amount of overlap and the angle (obliquity) of the impact. This approach was developed to more comprehensively identify small overlap crashes, which had been identified as a potential area for frontal impact crashworthiness enhancements.[309] Occupant inclusion requirements for the frontal target population consisted of belt-restrained occupants, who were not completely ejected, and who sustained an AIS 2+ injury or were killed. The seat positions and ages considered are summarized below:

Seat Row	Position	Age [years]
1	Outboard only (11,13)	13+
2	All (21,22,23)	8+

[307] See SAE J224, March 1980, Collision Deformation Classification for a guide to the acronyms used here.
[308] These are generic dimensions, by vehicle class, that are used as a guide for determining whether the damage is small overlap or not. See Bean, J., Kahane, C., Mynatt, M., Rudd, R., Rush, C., & Wiacek, C., National Highway Traffic Safety Administration, "Fatalities in Frontal Crashes Despite Seat Belts and Air Bags," DOT HS 811 202, September 2009 for more detail.
[309] Bean, J., Kahane, C., Mynatt, M., Rudd, R., Rush, C., & Wiacek, C., National Highway Traffic Safety Administration, "Fatalities in Frontal Crashes Despite Seat Belts and Air Bags," DOT HS 811 202, September 2009.

The first step in applying the FIT is to identify small overlap crashes based on the CDC alone for cases with damage described by GAD1 of F and SHL1 of L or R.[310] That subset of small overlap crashes is then augmented by the addition of crashes meeting a small overlap definition based on class-based vehicle geometry and crush. This crush-based assessment looks at the damage relative to the longitudinal frame rails for cases where the CDC may not indicate a small overlap impact based on the damage type coded by SHL1 (e.g., when SHL1 is either Y (left +center) or Z (right+center)). The frontal-oriented side plane impacts with GAD1 of L or R are examined from a crush perspective relative to vehicle class-specific geometry. In other words, when certain damage, and impact vector (PDOF) characteristics are met, the crash will be considered a small overlap frontal crash by the FIT. Frontal crashes not identified as small overlap at this stage are then classified based on the crush profile relative to the frame rail locations into left partial overlap, right partial overlap, or narrow center impacts if crush measures are defined. Remaining frontal crashes are considered full overlap.

After crashes have been classified based on the extent of overlap, they are categorized as either co-linear or oblique based on the coded PDOF value. All small overlap crashes, even with 0° PDOF angles, are considered oblique to the side of crush based on findings from laboratory research.[311] All full overlap and partial overlap crashes with non-zero PDOF angles are considered oblique. Full overlap crashes with 0° PDOF angle are considered co-linear. Partial overlap crashes with 0° PDOF angle are divided between oblique and co-linear based on findings of the study reported by Rudd et al. (2011). In that study, approximately 20 percent of the 0°

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[310] Ibid.
[311] Saunders, J. & Parent, D., "Repeatability of a Small Overlap and an Oblique Moving Deformable Barrier Test Procedure," SAE World Congress, Paper No. 2013-01-0762, 2013.

partial offset cases resulted in oblique occupant kinematics (to the side of crush).[312] Therefore, NASS-CDS case weights are apportioned 20 percent to oblique and 80 percent to co-linear for partial overlap 0° crashes. Note that the narrow center-impact partial overlap crashes are considered a special category, and will not be further broken into oblique or co-linear groups as they are not specifically addressed by any of the planned tests. For the purposes of this frontal target population, the crashes are further restricted to those with PDOF angles between 330° to 0° and 0° to 30°. There are no restrictions on the impacted object or on the model year of the case vehicle.[313]

The data are presented on an occupant basis, so the counts do not correspond to the number of vehicles meeting a particular crash description. There may be more than one occupant in a given vehicle. A tree diagram depicting the breakdown of the relevant frontal crash occupants considered in this analysis is provided in Figure I-1. The weighted 14-year total count of MAIS 2+ or fatal occupants in each level is shown. Data presented in this analysis have not been adjusted to account for air bag presence, changes in data collection procedures by case year, and to match fatality counts from the Fatality Analysis Reporting System (FARS). The counts presented are therefore only indicative of relative contributions – actual counts may differ.

Table I-1 shows counts of the occupants further broken down by MAIS 2+, MAIS 3+, or fatal and by seat row. Note that some fatally-injured occupants do not have injury data coded, and are therefore not represented in the MAIS 2+ or 3+ columns. This leads to small differences in calculated totals from Table I-1 and Figure I-1. Another difference between the counts shown

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[312] Rudd, R., Scarboro, M., & Saunders, J., "Injury Analysis of Real-World Small Overlap and Oblique Frontal Crashes," The 22nd International Technical Conference for the Enhanced Safety of Vehicles, Paper No. 11-0384, 2011.

[313] NHTSA is currently investigating this topic, and may revise its approach to categorizing frontal crashes as either co-linear or oblique.

in Figure I-1 and Table I-1 is that variant impacts, in which the PDOF angle is from the opposite side of the partial overlap, are merged into the "Other" category due to their unique occupant kinematics characteristics. Partial overlap crashes where the angle of obliquity is on the same side as the crush are considered coincident.[314]

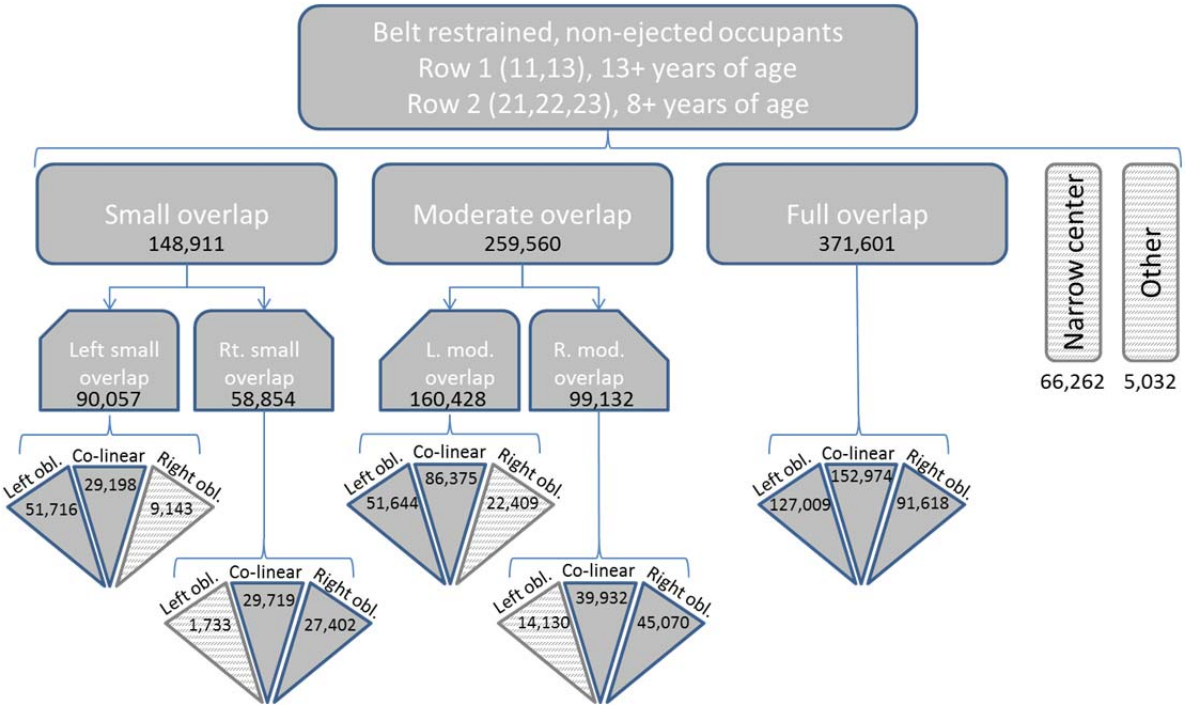

Figure I-1: Breakdown of MAIS 2+ or fatal frontal crash occupants by overlap and obliquity.
Counts represent weighted totals from 2000-2013 NASS-CDS.

Table I-1. Distribution of total weighted occupants for the fourteen year period by crash type (overlap) and obliquity for MAIS 2+, 3+, and fatal severity levels.

		Front Row			Second Row		
Overlap	Obliquity	MAIS 2+	MAIS 3+	Fatal	MAIS 2+	MAIS 3+	Fatal
Full	Co-linear	147,234	34,351	7,162	2,578	330	98
	Left	124,204	29,343	3,843	2,045	1,173	84
	Right	89,851	26,986	3,033	936	323	82
Left moderate	Co-linear	85,518	17,662	1,432	627	255	0
	Left	47,278	16,352	1,864	3,725	845	426
Right moderate	Co-linear	39,055	10,067	813	728	141	52

[314] Halloway, D., Pintar, F., Saunders, J., & Barsan-Anelli, A. (2012) "Classifiers to Augment the CDC System to Distinguish the Role of Structure in a Frontal Impact Taxonomy." SAE International Journal of Passenger Cars – Mechanical Systems, 5(2):778-788.

	Right	43,922	7,998	589	1,096	109	0
Left small	Co-linear	28,251	9,697	616	831	440	0
	Left	51,000	16,038	2,252	630	52	0
Right small	Co-linear	29,584	7,798	813	42	4	0
	Right	26,361	6,609	346	1,004	78	0
Narrow center	All angles	64,971	22,302	3,041	907	568	228
Other	*	51,574	10,187	1,241	817	250	0
Total		**828,803**	**215,390**	**27,045**	**15,966**	**4,568**	**970**

** Includes small and moderate overlap crashes with variant obliquity (e.g. left small overlap with right oblique PDOF angle). Source: NASS-CDS (2000-2013)*

With left and right partial overlap broken out into co-linear and coincident groups, the next step is to look at co-linear versus oblique crashes. The counts in Table I-1 are combined into co-linear full overlap, oblique, and co-linear moderate overlap groups and annualized by dividing by the number of case years (14) included in the analysis. It is important to note that Table I-2 does not distinguish between left and right oblique crashes – they are pooled together at this stage.

Table I-2. Distribution of occupants by crash obliquity for MAIS 2+, 3+, and fatal severity levels (annualized unadjusted occupants counts)

Crash Mode	**Front Row**			**Second Row**		
	MAIS 2+	*MAIS 3+*	*Fatal*	*MAIS 2+*	*MAIS 3+*	*Fatal*
Co-linear full overlap	10,517	2,454	512	184	24	7
Co-linear moderate overlap	8,898	1,981	160	97	28	4
Oblique	31,461	8,630	954	736	216	42
Narrow center	4,641	1,593	217	65	41	16
Other frontal*	3,684	728	89	58	18	0
Total	**59,200**	**15,385**	**1,932**	**1,140**	**326**	**69**

**Other frontal includes variant impacts and crashes that cannot be categorized due to missing data. Source: NASS-CDS (2000-2013)*

Left oblique and right oblique crashes are similar in that the occupants' trajectories are not straight forward relative to the vehicle interior, but the side of obliquity results in the near-side and far-side occupants experiencing different conditions (a driver would be considered a near-side occupant in a left oblique crash while the right front passenger would be a far-side occupant). Left oblique crashes represent a greater proportion of the oblique crashes, and Table

I-3 excludes the right oblique crashes (although 80% of the 0° right moderate overlap crashes have been accounted for in the co-linear full overlap category).

Table I-3. Distribution of occupants in left oblique and co-linear frontal crashes for MAIS 2+, 3+, and fatal severity levels (annualized unadjusted occupants counts)

Crash Mode	Front Row			Second Row		
	MAIS 2+	*MAIS 3+*	*Fatal*	*MAIS 2+*	*MAIS 3+*	*Fatal*
Co-linear full overlap	12,747	3,028	558	226	32	10
Co-linear left moderate overlap	6,108	1,262	102	45	18	0
Left oblique	17,910	5,102	613	517	179	36
Total	**36,765**	**9,392**	**1,273**	**787**	**229**	**46**

Source: NASS-CDS (2000-2013)

Applying the 80/20 rule previously described for the 0° left moderate overlap crashes leads to the counts shown in Table I-4, which shows the annualized target population for co-linear and left oblique frontal crashes. A graphical depiction of the distribution of MAIS 2+ counts is shown in Figure I-2. The counts shown are annualized, unadjusted counts, and represent the number of MAIS 2+, 3+, or fatal occupants in each crash and obliquity group.

Table I-4. Distribution of occupants in left oblique and co-linear frontal crashes for MAIS 2+, 3+, and fatal severity levels after redefining the dataset using NHTSA's approach on categorizing oblique crashes^

Crash Mode	Front Row			Second Row		
	MAIS 2+	*MAIS 3+*	*Fatal*	*MAIS 2+*	*MAIS 3+*	*Fatal*
Co-linear full overlap	17,634	4,037	640	261	46	10
Left oblique	19,131	5,354	633	525	183	36
Total	**36,765**	**9,392**	**1,273**	**787**	**229**	**46**

^ For the co-linear moderate overlap crashes, 20% were assigned to their respective oblique category with the remaining 80% being assigned to the co-linear category. Source: NASS-CDS (2000-2013)

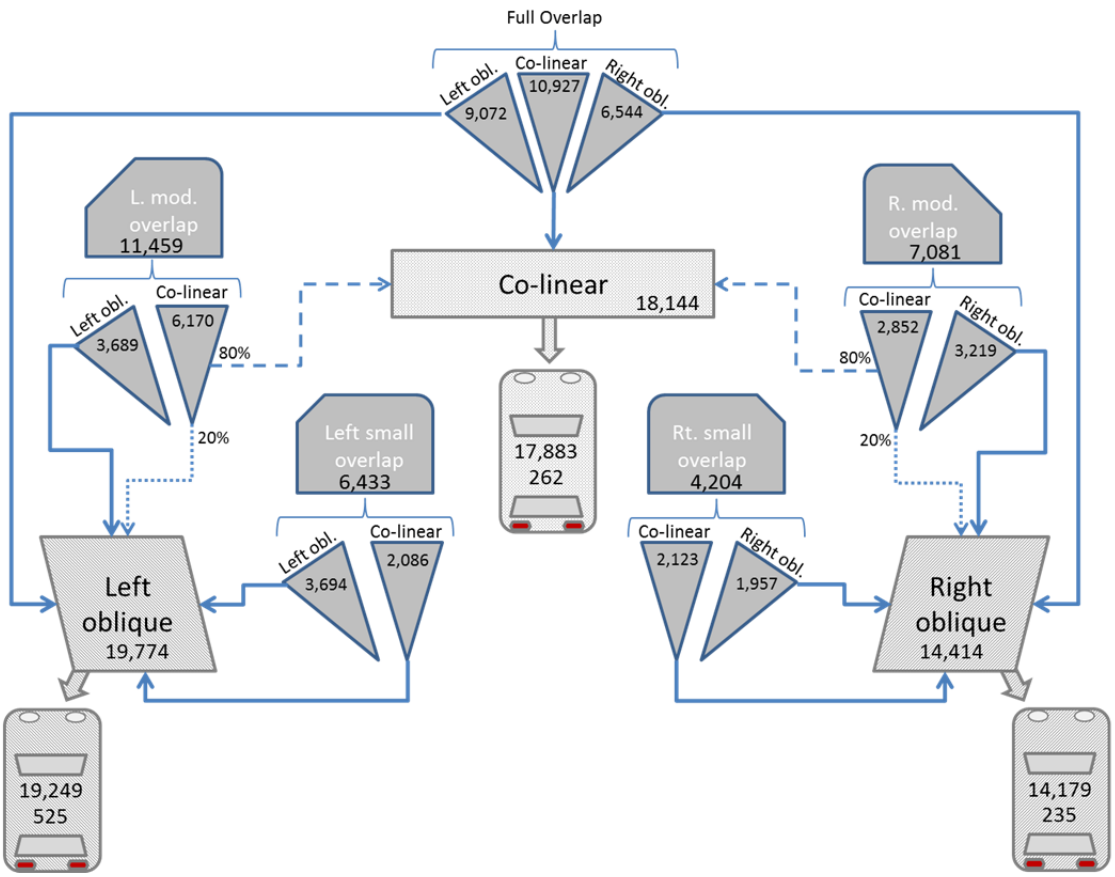

Figure I-2: Breakdown of MAIS 2+ or fatal frontal crash occupants by overlap and obliquity.
Counts represent weighted annualized totals from 2000-2013 NASS-CDS for front and second row occupants. Counts displayed are front row and second row combined, except in the vehicle diagrams that include the counts broken out by seat row.

Using the co-linear and left oblique crash groups described above, the injuries are examined in further detail by looking at counts of occupants sustaining MAIS 3+ injuries by body region. The body regions described below are based on the AIS body region identifier (first digit of AIS code) with some exceptions. The head includes face injuries, brain injuries (except brain stem), and skull fractures. The neck region includes soft tissue neck, cervical spine, brain stem, internal carotid artery, and vertebral artery injuries. The lower extremity is broken into a knee, thigh, hip (KTH) region and a below knee region.

Table I-5. Counts of occupants sustaining MAIS 3+ injuries by body region (annualized unadjusted occupants counts) in co-linear frontal crashes

Body Region	Driver	Right Front Passenger	Front Row Total	Second Row Left	Second Row Right	Second Row Total
Head	628	50	678	3	7	10
Neck & C-spine	214	20	234	1	2	3
Chest	1,629	250	1,879	4	11	15
Abdomen	325	37	362	3	11	14
Knee/Thigh/Hip	808	127	935	2	3	5
Below Knee	642	53	695	0	0	0
T&L-spine	242	19	261	4	4	8
Upper Extremity	564	140	704	2	0	2

Source: NASS-CDS (2000-2013)

Table I-6. Counts of occupants sustaining MAIS 3+ injuries by body region (annualized unadjusted occupants counts) in oblique frontal crashes

Body Region	Driver	Right Front Passenger	Front Row Total	Second Row Left	Second Row Right	Second Row Total
Head	696	76	771	66	14	80
Neck & C-spine	421	24	445	25	24	49
Chest	1,430	345	1,775	100	86	186
Abdomen	499	121	620	132	34	166
Knee/Thigh/Hip	1,285	133	1,418	30	8	38
Below Knee	1,012	26	1,038	80	3	83
T&L-spine	43	46	89	34	26	60
Upper Extremity	1,145	187	1,332	276	42	318

Source: NASS-CDS (2000-2013)

Appendix II: Planned THOR 50th Percentile Male Injury Risk Curves for Use in This NCAP Upgrade

Criterion [ref]	Calculation	Variable	Variable Definition	Risk Function
HIC_{15} [NCAP Final Decision Notice, 2008]	$HIC_{15} = \left\lvert (t_2 - t_1)\left[\frac{1}{(t_2 - t_1)}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}\right\rvert_{max}$	t_1	Beginning of time window in s	$p(AIS \geq 3) = \Phi\left[\frac{\ln(HIC_{15}) - 7.45231}{0.73998}\right]$
		t_2	End of time window in s	
		$a(t)$	Head CG resultant acceleration in g	
$BrIC$ [Takhounts, 2013]	$BrIC = \sqrt{\left(\frac{\max(\lvert\omega_x\rvert)}{\omega_{xC}}\right)^2 + \left(\frac{\max(\lvert\omega_y\rvert)}{\omega_{yC}}\right)^2 + \left(\frac{\max(\lvert\omega_z\rvert)}{\omega_{zC}}\right)^2}$	$\omega_{[x,y,z]}$	Angular velocity of the head about the local [x, y, or z] axis, in rad/s, filtered at CFC60	$p(AIS \geq 3) = 1 - e^{-\left(\frac{BrIC}{0.987}\right)^{2.84}}$
		$\omega_{[x,y,z]C}$	Critical angular velocities in rad/s	
		ω_{xC}	66.25 rad/s	
		ω_{yC}	56.45 rad/s	
		ω_{zC}	42.87 rad/s	
N_{ij} [Eppinger, 1999]	$N_{ij} = \frac{F_z}{F_{zc}} + \frac{M_y}{M_{yc}}$	F_z	Z-axis force measured at upper neck load cell in N	$p(AIS \geq 3) = \frac{1}{1 + e^{3.227 - 1.969N_{ij}}}$
		F_{zc}	Critical force (tension or compression) in N [2520/-3640]	
		M_y	Y-axis moment measured at upper neck load cell Nm	
		M_{yc}	Critical moment (flexion or extension) in Nm [48/-72]	
cN_{ij} [TBD]	$cN_{ij} = \frac{F_z}{F_{zc}} + \frac{M_y}{M_{yc}}$	F_z	Z-axis force measured at upper neck load cell in N	$p(AIS \geq 3) = 1 - e^{-\left(\frac{cN_{ij}}{0.83}\right)^{2.71}}$
		F_{zc}	Critical force (tension or compression) in N [3216/-4227]	
		M_y	Y-axis moment measured at upper neck load cell Nm	
		M_{yc}	Critical moment (flexion or extension) in Nm [67/-94]	
Multi-point	$R_{max} = max(UL_{max}, UR_{max}, LL_{max}, LR_{max})$	R_{max}	Overall peak resultant deflection in mm	$P(AIS \geq 3 \mid age, R_{max})$

Thoracic Injury Criterion – Peak Resultant Deflection [Crandall, 2013]	where $[U/L\|R/L]_{max} = max\left(\sqrt{[L/R]X^2_{[U/L]S} + [L/R]Y^2_{[U/L]S} + [L/R]Z^2_{[U/L]S}}\right)$	$[U/L\|R/L]_{max}$	Peak resultant deflection of the [upper/lower | left/right] quadrant in mm	$= 1 - exp\left(-\left[\frac{R_{max}}{exp(4.4853 - 0.0113age)}\right]^{5.0389}\right)$
		$[L/R][X/Y/Z]^2_{[U/L]S}$	Time-history of the [left/right] chest deflection along the [X/Y/Z] axis relative to the [upper/lower] spine segment in mm	
Multi-point Thoracic Injury Criterion – PC Score [Crandall, 2013]	$PCA\ Score = 0.485\left(\frac{up_{tot}}{17.509}\right) + 0.499\left(\frac{low_{tot}}{15.526}\right) + 0.493\left(\frac{up_{dif}}{10.479}\right) + 0.522\left(\frac{low_{dif}}{11.996}\right)$ $up_{tot} = \|UL\|_{max} + \|UR\|_{max}$ $up_{dif} = \|UL - UR\|_{max}$ $low_{tot} = \|LL\|_{max} + \|LR\|_{max}$ $low_{dif} = \|LL - LR\|_{max}$	up_{tot}	total upper chest resultant deflection, independent of time	$P(AIS3 + \| age, PCA\ Score) = 1 - exp\left(-\left[\frac{PCA\ Score}{exp(2.6092 - 0.0133age)}\right]^{4.4444}\right)$
		up_{dif}	maximum difference in upper chest left and right resultant deflection time-histories	
		low_{tot}	total lower chest resultant deflection, independent of time	
		low_{dif}	maximum difference in lower chest left and right resultant deflection time-histories	
Abdomen Compression [Kent, 2008]	$A_{max} = \frac{\max(\delta L, \delta R)}{d_{abd}}$	$\delta[L,R]$	Peak X-axis deflection of the left or right abdomen in mm	$p(AIS \geq 3) = 1 - e^{-\left(\frac{A_{max}}{0.4247}\right)^{3.6719}}$
		d_{abd}	Undeformed depth of the abdomen [238.4 mm]	
Acetabulum Load [Martin, 2011]	$F_R = \sqrt{{F_x}^2 + {F_y}^2 + {F_z}^2}$	$F_{[x,y,z]}$	X-, Y-, and Z- axis force measured at the acetabulum load cell in kN	$p(AIS \geq 3) = \Phi\left[\frac{\ln(1.3F_R) - 1.6526}{0.1991}\right]$
Femur Axial Load [Kuppa, 2001]		F_z	Z-axis femur load in kN, filtered at CFC600	$p(AIS \geq 2) = \frac{1}{1 + e^{5.7949 - 0.5196F_z}}$
Revised Tibia Index [Kuppa, 2001]	$RTI = \frac{F}{F_c} + \frac{M}{M_c}$	F	Measured compressive axial force in kN	$p(AIS \geq 2) = 1 - exp\left(-exp\left[\frac{ln(RTI) - 0.2468}{0.2728}\right]\right)$
		F_c	Critical compressive axial force [12 kN]	
		M	Measured bending moment in Nm (resultant of medial-lateral and anterior-posterior directions)	
		M_c	Critical bending moment [240 Nm]	

Distal Tibia Axial Force [Kuppa, 2001]		F_z	Z-axis lower tibia load in kN, filtered at CFC600	$p(AIS \geq 2) = \frac{1}{1 + e^{4.572 - 0.670 F_z}}$
Proximal Tibia Axial Force [Kuppa, 2001]		F_z	Z-axis upper tibia load in kN, filtered at CFC600	$p(AIS \geq 2) = \frac{1}{1 + e^{5.6654 - 0.8189 F_z}}$
Dorsiflexion Moment [Kuppa, 2001]	$M_{y_{ankle}} = M_Y - F_x D - \frac{m a_x D}{2}$	M_Y	Y-axis moment measured at lower tibia load cell in Nm	$p(AIS \geq 2) = \frac{1}{1 + e^{6.535 - 0.1085 M_y}}$
		F_x	X-axis force measured at lower tibia load cell in N	
		D	Distance between ankle joint and lower tibia load cell [0.0907m]	
		m	Mass between ankle joint and lower tibia load cell [0.72kg]	
		a_x	X-axis acceleration of the tibia in m/s^2	
Inversion/ Eversion Moment [Kuppa, 2001]	$M_{x_{ankle}} = M_x - F_y D - \frac{m a_y D}{2}$	M_x	X-axis moment measured at lower tibia load cell in Nm	$p(AIS \geq 2) = \Phi\left[\frac{M_x - 40Nm}{10Nm}\right]$
		F_y	Y-axis force measured at lower tibia load cell in N	
		D	Distance between ankle joint and lower tibia load cell [0.0907m]	
		m	Mass between ankle joint and lower tibia load cell [0.72kg]	
		a_y	Y-axis acceleration of the tibia in m/s^2	

Appendix III: Planned Hybrid III 5th Percentile Female Injury Risk Curves for Use in this NCAP Upgrade

Criterion [ref]	Calculation	Variables	Variable Definition	Risk Function
HIC_{15} [NCAP Final Decision Notice, 2008]	$HIC_{15} = \left\lvert (t_2 - t_1)\left[\frac{1}{(t_2 - t_1)}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}\right\rvert_{max}$	t_1	Beginning of time window in s	$p(AIS \geq 3) = \Phi\left[\frac{\ln(HIC_{15}) - 7.45231}{0.73998}\right]$
		t_2	End of time window in s	
		$a(t)$	Head CG resultant acceleration in g	
$BrIC$ [Takhounts, 2013]	$BrIC = \sqrt{\left(\frac{\max(\lvert\omega_x\rvert)}{\omega_{xC}}\right)^2 + \left(\frac{\max(\lvert\omega_y\rvert)}{\omega_{yC}}\right)^2 + \left(\frac{\max(\lvert\omega_z\rvert)}{\omega_{zC}}\right)^2}$	$\omega_{[x,y,z]}$	Angular velocity of the head about the local [x, y, or z] axis, in rad/s, filtered at CFC60	$p(AIS \geq 3) = 1 - e^{-\left(\frac{BrIC}{0.987}\right)^{2.84}}$
		$\omega_{[x,y,z]C}$	Critical angular velocities in rad/s	
		ω_{xC}	66.25 rad/s	
		ω_{yC}	56.45 rad/s	
		ω_{zC}	42.87 rad/s	
Neck Tension or Compression [NCAP Final Decision Notice, 2008]		F_z	Z-axis force measured at upper neck load cell in kN	$p(AIS \geq 3) = \frac{1}{1 + e^{10.958 - 3.770F_z}}$
N_{ij}	$N_{ij} = \frac{F_z}{F_{zc}} + \frac{M_y}{M_{yc}}$	F_z	Z-axis force measured at upper neck load cell in N	$p(AIS \geq 3) = 1 - e^{\left(-\left(\frac{N_{ij}}{1.3933}\right)^{2.8816}\right)}$
		F_{zc}	Critical force (tension or compression) in N [4287/-3880]	
		M_y	Y-axis moment measured at upper neck load cell Nm	
		M_{yc}	Critical moment (flexion or extension) in Nm [155/-67]	

Chest Deflection [NCAP Final Decision Notice, 2008]		δ	Peak X-axis deflection at chest potentiometer in mm	$p(AIS \geq 3) = \frac{1}{1 + e^{12.597 - 0.05861 * 35 - 1.568 * (\frac{\delta}{0.817})^{0.4612}}}$
Femur Axial Force [NCAP Final Decision Notice, 2008]		F_z	Z-axis femur force in kN	$p(AIS \geq 2) = \frac{1}{1 + e^{5.7949 - 0.7619 F_z}}$

Appendix IV: Planned WorldSID 50th Percentile Male Injury Risk Curves for Use in This NCAP Upgrade

Criterion [ref]	Calculation	Variables	Variable Definition	Risk Function
HIC_{36} [NCAP Final Decision Notice, 2008]	$HIC_{36} = \left\lvert (t_2 - t_1)\left[\frac{1}{(t_2 - t_1)}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}\right\rvert_{max}$	t_1	Beginning of time window in s	$p(AIS \geq 3) = \Phi\left[\frac{\ln(HIC_{36}) - 7.45231}{0.73998}\right]$
		t_2	End of time window in s	
		$a(t)$	Head CG resultant acceleration in g	
$BrIC$ [Takhounts, 2013]	$BrIC = \sqrt{\left(\frac{\max(\lvert\omega_x\rvert)}{\omega_{xC}}\right)^2 + \left(\frac{\max(\lvert\omega_y\rvert)}{\omega_{yC}}\right)^2 + \left(\frac{\max(\lvert\omega_z\rvert)}{\omega_{zC}}\right)^2}$	$\omega_{[x,y,z]}$	Angular velocity of the head about the local [x, y, or z] axis, in rad/s, filtered at CFC60	$p(AIS \geq 3) = 1 - e^{-\left(\frac{BrIC}{0.987}\right)^{2.84}}$
		$\omega_{[x,y,z]C}$	Critical angular velocities in rad/s	
		ω_{xC}	66.25 rad/s	
		ω_{yC}	56.45 rad/s	
		ω_{zC}	42.87 rad/s	
Shoulder Force [Petitjean, 2012]		F_Y	Y-axis maximum shoulder load in N, filtered at CFC600	$p(AIS \geq 2) = 1 - e^{-\left(\frac{F_Y}{8.144 - 0.006age}\right)^{7.41}}$
Skeletal Thoracic Injury [Petitjean, 2012]		δ_{max}	Y-axis maximum thoracic or abdominal rib deflection in *mm*, filtered at CFC600	$p(AIS \geq 3) = \frac{1}{1 + e^{\left(\frac{-(\ln(\delta_{\max}) - (4.670 - 0.015age))}{0.123}\right)}}$
Soft Tissue Abdominal Injury [Petitjean, 2012]		δ_{max}	Y-axis maximum abdominal rib deflection in *mm*, filtered at CFC600	$p(AIS \geq 2) = 1 - e^{-\left(\frac{\delta_{max}}{5.368 - 0.021age}\right)^{8.61}}$
Pubic Force [Petitjean, 2012]		F_Y	Y-axis pubic force in N, filtered at CFC600	$p(AIS \geq 2) = 1 - e^{-\left(\frac{F_Y}{8.775 - 0.014age}\right)^{4.60}}$

Appendix V: WorldSID-50M and WorldSID-5F NHTSA Test Numbers

Table 1. Test Numbers of NHTSA WorldSID-50M and WorldSID-5F Tests

					Test Numbers	
	Size	**Year**	**Make**	**Model**	**Pole**	**MDB**
Passenger Car	Compact	2010	Suzuki	SX4	7658	8349
		2010	Kia	Forte	7657	8348
	Mid-Size	2011	Hyundai	Sonata	7653	8351
		2010	Buick	LaCrosse	7654	8352
	Large	2011	Cadillac	CTS	7661	8346
SUV/ Crossover	Compact	2011	Hyundai	Tucson	7659	8347
	Mid-Size	2011	Acura	MDX	7656	8353
		2010	Chevy	Traverse	7655	Not tested
	Large	2011	Jeep	Grand Cherokee	7660	8345
		2011	Ford	Explorer	7662	8344
Truck	Mid-Size	2010	Ford	F150	7652	8343
Van		2011	Honda	Odyssey	7663	8350
Other		2012	Chevy	Traverse	Not tested	8354

Appendix VI: Planned SID-IIs 5th Percentile Female Injury Risk Curves for Use in this NCAP Upgrade

Criterion [ref]	Calculation	Variables	Variable Definition	Risk Function
HIC_{36} [NCAP Final Decision Notice, 2008]	$HIC_{36} = \left\lvert (t_2 - t_1)\left[\frac{1}{(t_2 - t_1)}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}\right\rvert_{max}$	t_1	Beginning of time window in s	$p(AIS \geq 3) = \Phi\left[\frac{\ln(HIC_{36}) - 7.45231}{0.73998}\right]$
		t_2	End of time window in s	
		$a(t)$	Head CG resultant acceleration in g	
$BrIC$ [Takhounts, 2013]	$BrIC = \sqrt{\left(\frac{\max(\lvert\omega_x\rvert)}{\omega_{xC}}\right)^2 + \left(\frac{\max(\lvert\omega_y\rvert)}{\omega_{yC}}\right)^2 + \left(\frac{\max(\lvert\omega_z\rvert)}{\omega_{zC}}\right)^2}$	$\omega_{[x,y,z]}$	Angular velocity of the head about the local [x, y, or z] axis, in rad/s, filtered at CFC60	$p(AIS \geq 3) = 1 - e^{-\left(\frac{BrIC}{0.987}\right)^{2.84}}$
		$\omega_{[x,y,z]C}$	Critical angular velocities in rad/s	
		ω_{xC}	66.25 rad/s	
		ω_{yC}	56.45 rad/s	
		ω_{zC}	42.87 rad/s	
Thoracic Rib Deflection [Kuppa, 2006]		δ_{max}	Y-axis maximum thoracic rib deflection in *mm*, filtered at CFC600	$p(AIS \geq 3) = \frac{1}{1 + e^{5.8627 - 0.15498 * \delta_{max}}}$
Abdominal Rib Deflection [Kuppa, 2006]		δ_{max}	Y-axis maximum abdomen rib deflection in *mm*, filtered at CFC600	$p(AIS \geq 4) = \frac{1}{1 + e^{8.9798 - 0.1349 * \delta_{max}}}$
$Acetabular + Iliac\ Force$ [NCAP Final Decision Notice, 2008]	$F_T = F_{Ya} + F_{Yi}$	F_{Ya}	Y-axis acetabular load in *N*, filtered at CFC600	$p(AIS \geq 2) = \frac{1}{1 + e^{6.3055 - 0.00094 * F_T}}$ *where F_T is the total sum of the acetabular and iliac force in Newtons*
		F_{Yi}	Y-axis iliac load in *N*, filtered at CFC600	

Appendix VII: Pedestrian Data

Table VII-1: Pedestrian injuries and fatalities in single-vehicle crashes by vehicle type, 2012

Applicable vehicles	Class of Vehicle	Injuries		Fatalities	
Covered by proposed pedestrian safety regulation	Passenger cars	30,071	48,373	1,781	2,879
	Minivans	3,476		218	
	Cross-over vehicles	3,776		270	
	Small SUVs and pickups	11,050		610	
	Large SUVs and vans	4,960	11,811	308	839
	Large pickup trucks	6,851		531	
Not covered	Large trucks or buses	2,202		445	
	Motorcycles	641		29	
	Unknown vehicle	9,149		626	
	Totals	72,176		4,818	

Sources: NHTSA's Fatality Analysis Reporting System (FARS) and National Automotive Sampling System - General Estimates System (NASS GES)

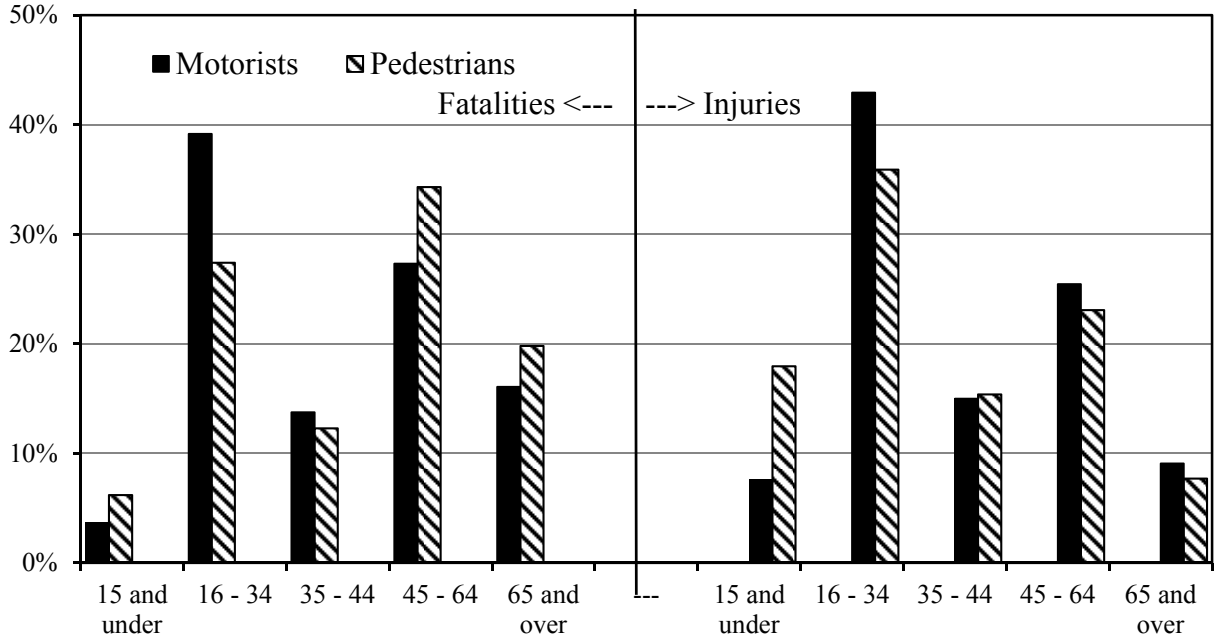

Figure VII-1: Percentage of U.S. traffic fatalities and injuries by age, 2012

Sources: FARS and GES

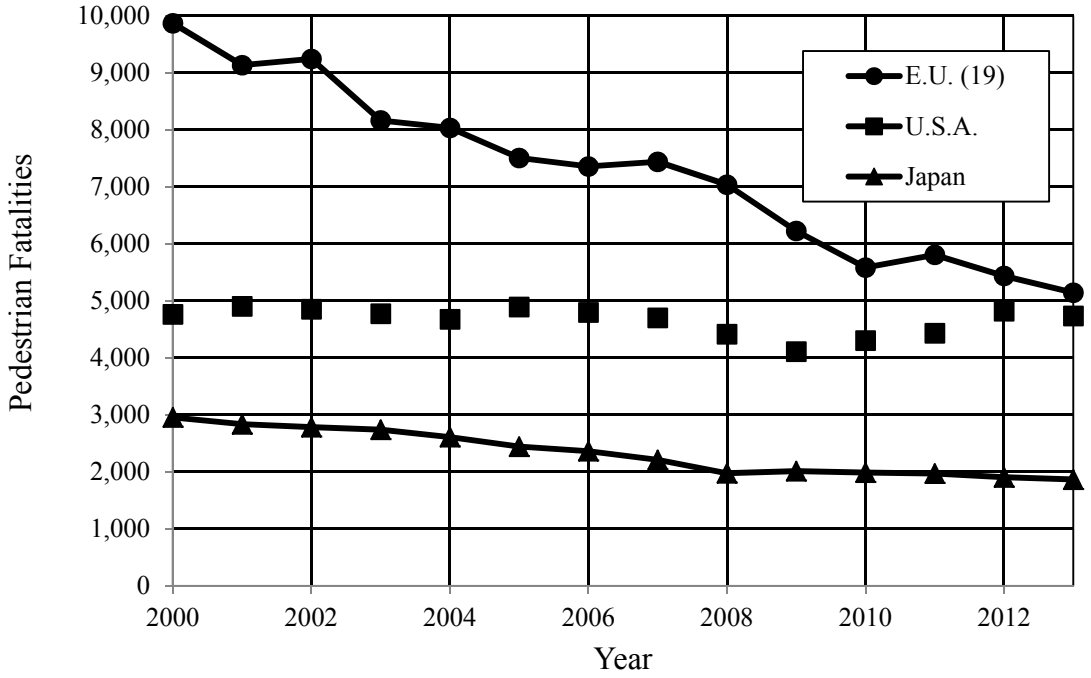

Figure VII-2: Pedestrian fatality trends in Europe, the U.S., and Japan

Sources: FARS (U.S.), European Road Safety Observatory (E.U.), Institute for Traffic Accidents Research and Data Analysis (Japan)

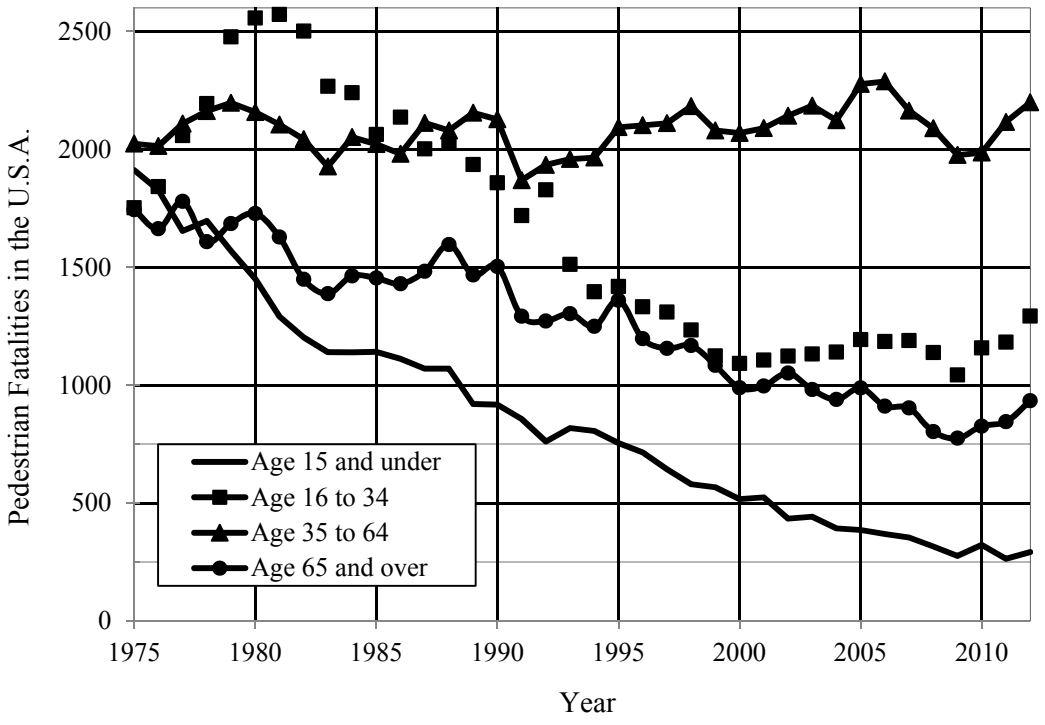

Figure VII-3: Year-by year pedestrian fatalities in the U.S., 1975 onward

Source: FARS

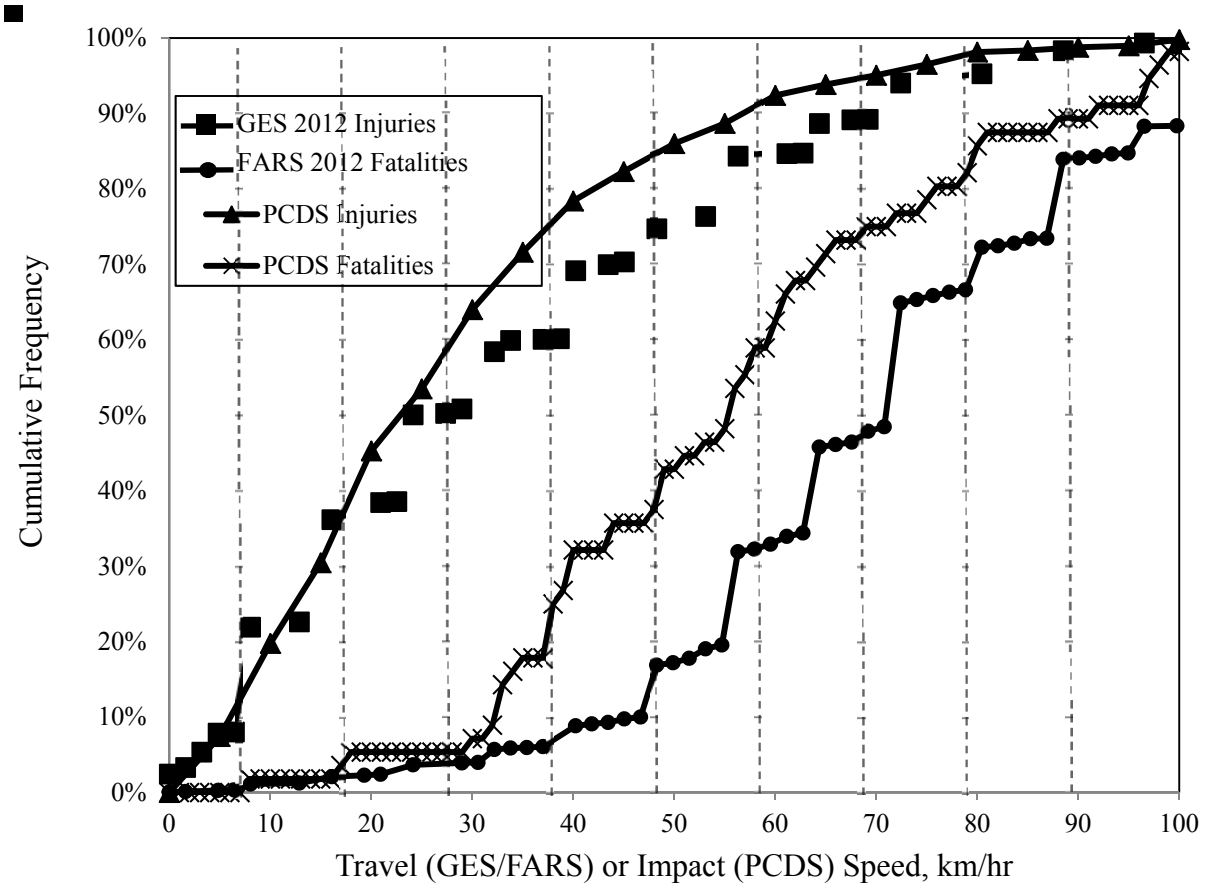

Figure VII-4: PCDS (1994-1998) and FARS/GES (2012) speed distributions for pedestrian fatalities
Sources: FARS/GES, 2012. PCDS (NHTSA)

Appendix VIII: Crash Avoidance Test Procedures

Crash Avoidance test procedures discussed in this Request for Comment may be found in the docket identified at the beginning of this RFC notice. Duplicate copies of test procedures already incorporated into the NCAP program will also reside at the NHTSA website via this link: *www.safercar.gov/Vehicle+Shoppers/5-Star+Safety+Ratings/NCAP+Test+Procedures*.

Crash Avoidance Technology	Test Procedure	Status
Amber Rear Turn Signal Lamps	Amber Rear Turn Signal Lamps Confirmation Test for NCAP (Working Draft), December 2015	New, Draft
Blind Spot Detection	Blind Spot Detection System Confirmation Test (Working Draft), December 2015	New, Draft
Crash Imminent Braking	Crash Imminent Brake System Performance Evaluation for NCAP (Working Draft), September 2015	Existing
Dynamic Brake Support	Dynamic Brake Support System Performance Evaluation Confirmation Test, September 2015	Existing
Forward Collision Warning	Forward Collision Warning System Confirmation Test (February 2013)	Existing
Lane Departure Warning	Lane Departure Warning System Confirmation Test and Lane Keeping Support Performance Documentation (February 2013)	Existing
Lower Beam Headlighting	Lower Beam Headlighting Visibility Confirmation Test (December 2015)	New, Draft
Rear automatic braking	Rear Automatic Braking Feature Confirmation Test Procedure (December 2015)	New, Draft
Rollover Resistance	Laboratory Test Procedure for Dynamic Rollover, The Fishhook Maneuver Test Procedure (March 2013)	Existing
	Laboratory Test Procedure for Rollover Stability Measurement for NCAP Static Stability Factor (SSF) Measurement (March 2013)	Existing
Semi-automatic Headlamp Beam Switching	Semiautomatic Headlamp Beam Switching Device Confirmation Test (Working Draft), December 2015	New, Draft

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Administrator

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