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FINAL REGULATORY IMPACT ANALYSIS

FMVSS NO. 214

AMENDING SIDE IMPACT DYNAMIC TEST

ADDING OBLIQUE POLE TEST

OFFICE OF REGULATORY ANALYSIS AND EVALUATION
NATIONAL CENTER FOR STATISTICS AND ANALYSIS
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TABLE OF CONTENTS

Appendices

EXECUTIVE SUMMARY

This Final Regulatory Impact Analysis analyzes the potential impacts of new performance requirements and test procedures for head and thorax protection systems in side crashes. The intent of this rulemaking is to improve occupant protection for belted and unbelted occupants in side crashes.

Test Requirements

The rule requires a new 20 mph, 75-degree oblique pole test run in two different configurations, one with a 50th percentile male (ES-2re) dummy and the other with a 5th percentile female (SID-IIs Build D) dummy. In addition to the oblique pole test, the rule requires a test with the ES-2re in the front seat and the SID-IIs Build D in the rear seat in the moving deformable barrier (MDB) dynamic FMVSS 214 side impact test, in place of the test with two 50th percentile male side impact dummies on the struck side of the vehicle (49 CFR Part 572 Subpart F (SID).

Countermeasures

The agency believes that side air bags for the head and thorax will be used to pass the tests and that most manufacturers will have to make their current side air bags wider to pass the oblique test. We analyzed the costs and benefits of three countermeasures: (1) the combination head/thorax side air bag, 2 sensor system, (2) the window curtain plus a separate thorax side air bag, 2 sensor system, (3) the window curtain plus a separate thorax side air bag, 4 sensor system. Combination air bags and thorax air bags are assumed for front seat occupants only, window curtains are assumed to provide head protection for both front and rear seat occupants. The agency believes the most likely countermeasure used by manufacturers will be a window curtain and separate thorax side air bag system with 2-sensors per vehicle.

A few vehicles failed the moving deformable barrier test with the 5th percentile female dummy. The agency did not test any specific countermeasures to assure that these failing vehicles could pass the 5th percentile female moving deformable barrier (MDB) test. However, based on the MDB test results we believe that minor design changes such as the addition of door padding, improved armrest designs, and larger window curtains that come down to the window sill area, will lead to better protection for smaller occupants. This test will help assure that smaller sized occupants are protected to the same extent as the 50th percentile male occupants.

Benefits

The agency estimates benefits for occupants in outboard seating positions in near-side crashes of 12-25 mph delta-V in vehicle-to-pole and vehicle-to-vehicle crashes. The agency has also found that the side air bags provide benefits to unbelted far-side occupants in side impacts and for belted drivers riding alone in the front seat.

After adjusting for assumed full compliance with the FMVSS 201 upper interior requirements, 100% Electronic Stability Control (ESC) penetration and manufacturer's planned side air bag sales[1] in the model (MY) 2011 vehicle fleet, and current compliance

[1] Seven manufacturers (comprising about 90 percent of all light vehicle sales) responded confidentially to a NHTSA request for planned side air bag installations and projected sales through model year (MY) 2011. For remaining manufacturers, MY 2006 side air bag percentages were assumed to remain constant through MY 2011.

with the final rule (based on testing recent vehicles with side air bags), the incremental benefits of the final rule are estimated as shown in the following table.

Benefits of the Final Rule by Countermeasure[2]

	Combination Air Bag 2 Sensors	**Curtain & Thorax Bags 2 Sensors**	**Curtain & Thorax Bags 4 Sensors**
Fatalities	266	311	311
AIS 3-5 Injuries	352	361	371

Window curtains are estimated to have more benefits than combination air bags because we assume that window curtains will cover and provide protection for occupants in the rear seating positions. On the other hand, if a combination air bag is provided in the front, the pole test does not require a countermeasure for the rear seat and we assume no benefits for combination air bags in rear near-side impacts. Curtain and combination air bags probably will have some benefit in non-rollover complete ejections, but the agency has no way to estimate their benefit at this time. No benefits are claimed for ejections in rollovers, since the test does not check the effectiveness of a combination air bag or window curtain to contain occupants in a rollover event. The majority of the benefits are for front seat occupants, but a small number of benefits (5 fatalities and 18 AIS 3+ from window curtains reducing head impacts and one AIS 3 pelvic injury in the MDB test) were estimated for rear seat occupants.

[2] The benefits of 100 percent of the fleet having side air bags compared to 0 percent of the fleet having side air bags, assuming 100 percent of vehicles have Electronic Stability Control systems, are estimated to be 976 fatalities and 932 AIS 3-5 injuries.

Costs

Potential compliance costs for the pole test vary considerably and are dependent upon the types of head and thorax side air bags chosen by the manufacturers and the number of sensors used in the system. The costs for installing new systems range from wide combination head/thorax side air bags with two sensors at $126 per vehicle to wide window curtains and wide thorax side air bags with four sensors at a cost of $280 per vehicle. Given the level of compliance in the MY 2005 fleet the average vehicle incremental cost to meet this final rule, over the manufacturer's plans for side air bags in MY 2011, with the lower cost combination air bag is estimated to be $25 per vehicle and with the wide window curtains and wide thorax side air bags with four sensors is estimated to be $66 per vehicle (2004 dollars). This amounts to a range of total incremental annual costs of $429 million to $1.1 billion.

Incremental Total Costs and Average Vehicle Costs
($2004)

	Combination Head/Thorax Side Air Bags	**Window Curtain and Thorax Side Air Bags, 2 Sensors**	**Window Curtain and Thorax Side Air Bags, 4 Sensors**
Incremental Total Costs	$429 million	$560 million	$1.1 billion
Average Incremental Cost per Vehicle	$25	$33	$66
Total Vehicle Cost per New System	$126	$243	$280

Cost Per Equivalent Life Saved and Net Benefits

Estimates were made of the costs per equivalent life saved. The low end of the range is $1.6 million per equivalent life saved, using a 3 percent discount rate, assuming manufacturers currently with no side air bags or only thorax side air bags install combination head/thorax air bags rather than separate window curtains and thorax air bags. The high end of the range is $4.6 million per equivalent life saved, using a 7 percent discount rate, assuming the manufacturers install separate window curtains and thorax air bags with four sensors.

Costs Per Equivalent Life Saved
Present Discounted Value

Cost Per Equivalent Life Saved	Combination Head/Thorax Side Air Bags	Window Curtain and Thorax Side Air Bags, 2 Sensors	Window Curtain and Thorax Side Air Bags, 4 Sensors
3% Discount Rate	$1.6 million	$1.8 million	$3.7 million
7% Discount Rate	$2.0 million	$2.3 million	$4.6 million

Net benefit analysis differs from cost effectiveness analysis in that it requires that benefits be assigned a monetary value, and that this value is compared to the monetary value of costs to derive a net benefit. The high end of the net benefits is $567 million for the curtain + thorax bags with two sensors using a 3 percent discount rate and the low end is negative $225 million for the curtain + thorax bags with four sensors, using a 7 percent discount rate. Both of these are based on a $3.7 million cost per life, as shown below.

Net Benefits
With $3.7M Cost Per Life
(in millions)

Countermeasure	Benefit		Net Benefit	
	3% discount	7% discount	3% discount	7% discount
Combo + 2 Sensors	$990	$787	$561	$357
Curtain + 2 Sensors	$1,127	$895	$567	$336
Curtain + 4 Sensors	$1,131	$899	$7	-$225

Uncertainty Analysis

Since there are uncertainties within the test results, the test procedures, the links between test data and real world applicability, the countermeasures to be used, etc., uncertainties are inherent in the cost-effectiveness and net benefit analyses. We have identified the uncertainties and described them with degrees of probability or plausibility. We analyzed the potential impact that important uncertainties have on the results of the analysis. We found for the combination head/thorax air bag a 100% certainty that the cost per equivalent life saved will be less than $3.7 million and for the separate window curtain/side thorax air bag with two sensors we found 99% certainty that the cost per equivalent life saved will be less than $3.7 million at a 7% discount rate. In addition, the analysis shows that the separate window curtain/side thorax air bag with four sensors would have an 86 percent chance to produce a cost per equivalent life saved of no more than $5.5 million.

Leadtime

Based on the final rule, the manufacturers would have to test their vehicles with the oblique pole test and determine whether they need changes in their current countermeasures. We believe the most cost-effective way to accomplish the redesign task is to allow a phase-in of the requirements. The effective date for both the MDB and the oblique pole tests is shown below:

Final Rule Phase-In Schedule

Phase-in Date	Percent of each manufacturer's light vehicles that must comply during the production period
September 1, 2009 to August 31, 2010	20 percent (excluding vehicles GVWR > 8,500 lbs.)
September 1, 2010 to August 31, 2011	50 percent vehicles (excluding vehicles GVWR > 8,500 lbs.)
September 1, 2011 to August 31, 2012	75 percent vehicles (excluding vehicles GVWR > 8,500 lbs.)
September 1, 2012 to August 31, 2013	All vehicles including limited line vehicles, except vehicles with GVWR > 8,500 lbs., alterers, and multi-stage manufacturers
On or after September 1, 2013	All vehicles, including vehicles with GVWR > 8,500 lbs., alterers and multi-stage manufacturers

INTRODUCTION

In 1990, the agency amended its side impact protection standard (FMVSS 214) by adding a new dynamic test applicable to passenger cars. In 1995, the dynamic test was extended to most light trucks[3] with a gross vehicle weight rating (GVWR) of 2,722 kg (6,000 pounds) or less. This test currently provides protection against thoracic and pelvic injuries in a moving deformable barrier test simulating a moving vehicle being struck in the side at 90 degrees by another moving vehicle. Side impact dummies (the SID dummy representing a 50th percentile male) are positioned in the front and rear seat on the side of the vehicle struck by the moving deformable barrier.

Head injuries are a major cause of fatalities in side impacts, whereas chest injuries are the predominant cause of AIS 3-5 non-fatal injuries. However, there is no head injury requirement in the dynamic FMVSS No. 214 test. Typically, the moving deformable barrier hits below the dummy's head, the window breaks, the dummy's head goes out the window, but does not strike the barrier. Thus, the measured head injury criterion (HIC) tends to be low in this dynamic test. Yet, in the real world, many people are killed or seriously injured by head injuries in side impacts.

In 1995, NHTSA issued a final rule amending FMVSS No. 201, "Occupant Protection in Interior Impact," to require passenger cars, and trucks, buses and multipurpose passenger vehicles with a gross vehicle weight rating of 4,536 kg (10,000 lb) or less, to provide protection when an occupant's head strikes certain upper interior components, including

[3] "Light trucks" include multi-purpose passenger vehicles (vans and sport-utility vehicles) and trucks (pickups). The term "passenger vehicles" includes passenger cars and light trucks.

pillars, side rails, headers, and the roof, during a crash. This final rule was aimed at all crash modes. The performance test is a free-motion headform propelled at specific target points in the vehicle at 15 mph.

In 1998, NHTSA published a final rule amending Standard 201 to permit, but not require, the installation of a dynamically deploying upper interior head protection system. Manufacturers choosing the option of installing a dynamically deployed head protection system had to subject their vehicles to the same free-motion headform test but at a reduced speed of 12 mph (rather than 15 mph) at those target points near the stowed deployable head airbag system. In addition, the vehicle had to meet a 29 kph (18 mph) perpendicular vehicle-to-pole test.

Even with Standards No. 214 and 201, there are still a large number of fatalities occurring in side impacts resulting from a variety of crash types and outcomes. Fatalities are occurring when an occupant strikes a tree or pole, when the striking vehicle has a high front end (a taller pickup, SUV, or a heavy truck), when the occupant is ejected out the side window, and when the crash is of high speed/ high severity, even when the striking vehicle is a passenger car.

Through the work of automobile manufacturers and their suppliers, countermeasures have been introduced that appear to be effective in reducing fatalities in several of these crash types.

The final rule will substantially upgrade FMVSS 214 by requiring all passenger vehicles with a GVWR of 4,536 kilograms (10,000 pounds) or less to provide protection in a vehicle-to-pole test simulating a vehicle crashing sideways into a narrow fixed object like a telephone pole or tree. The pole test will be conducted using a 5th percentile female dummy (SID-IIs Build D) seated full-forward or a 50th percentile male dummy (ES-2re) seated at the mid-track position of the front outboard driver or passenger seats. The agency is also requiring that the 50th percentile male be used in the front outboard seating positions and the 5th percentile female be used in the rear outboard seating positions in the MDB test configuration required by FMVSS 214.

This Final Regulatory Impact Analysis presents the agency's estimates of the potential benefits and costs of countermeasures that could be used to meet the pole test requirements. It provides analysis of the different dummies that are used during the test and discusses the injury criteria. It provides analyses of the different tests and alternatives the agency considered. Finally, it estimates the cost per equivalent life saved.

II. BACKGROUND

Test Requirements

Vehicles have side impacts with a variety of different objects, including poles and trees and other vehicles of the same or different type as the impacting vehicle. These crashes can pose different risks of injury to vehicle occupants. There is also the risk of injury from being ejected in a side crash, even crashes not involving vehicle rollover. To address these concerns, NHTSA is requiring vehicles to meet an oblique pole test in which the vehicle is propelled into a rigid 254 mm (10-inche) diameter pole. The pole is aimed at the head of a front seat occupant (either the driver or right front passenger) using crash dummies representing a 50th percentile male (ES2-re) and 5th percentile female (SID-IIs).

In the NPRM, the agency proposed to use a SID-IIs Build C small female test dummy to which the agency had added "floating rib guide" (FRG) components to increase the durability of the dummy. The dummy with the FRG modification was called the "SID-IIsFRG." Comments to the NPRM maintained that the entirety of the FRG modifications was unnecessary, and that the totality of the FRG modifications needlessly reduced the biofidelity and functionality of the dummy. Some commenters suggested alternative means of improving the durability of the Build Level C dummy. Upon consideration, we have decided to adopt some but not all of the FRG modifications, and to adopt the commenters' alternative suggested revisions to Build Level C. The SID-IIs dummy adopted today is referred to as the SID-IIs "Build Level D" crash test dummy. Build

Level D incorporates features stemming from the FRG and from users' efforts to enhance the functionality of predecessor SID-IIs dummies.

The oblique pole test requires protection for the head, chest, abdomen and pelvis at a vehicle delta-V of 32.2 kph (20 mph). For this analysis, it is assumed that manufacturers will choose a head and torso air bag system to meet the requirements.

In addition to the oblique pole test, the agency is requiring the ES-2re, 50th percentile male dummy be used in the front seat of the moving deformable barrier (MDB) dynamic FMVSS No. 214 side impact test, and additionally, include a 5th percentile female dummy (the SID-IIs) in the rear seat of the MDB test. The injury criteria in the MDB test are the same as those required for the vehicle-to-pole test.

DUMMIES

The 1990 amendment to FMVSS No. 214 used a 50th percentile male Side Impact Dummy (SID) in the dynamic MDB test. SID measures acceleration in the chest and pelvis. The agency has concluded that the 50th percentile male ES-2re dummy is considerably more biofidelic and offers more injury measurement capabilities than the present side impact dummy (SID).

The agency also finds that small stature occupants have injury patterns that differ from those of medium stature occupants[4]. Therefore, the agency adopts a 5th percentile female SID-IIs crash test dummy for use in both the vehicle-to-pole and MDB tests.

Countermeasures

There are many different types of head and side air bags that have been voluntarily introduced into new vehicles. One of these types is a curtain (alternatively, "air curtain" or "window curtain") system. The curtain system provides head protection for front and possibly rear seat occupants in outboard seating positions in side crashes, as the air bags are designed to deploy down from a vehicle's roof rail. A second type is the Inflatable Tubular Structure (ITS). The ITS is an inflatable device that is also installed under the roof rail headliner and deploys down like the curtain system. The ITS is fixed at two points, one at the front of the vehicle's A-pillar and the other at the back end to the roof rail behind the B-pillar. When deployed, the ITS inflates to become a self supporting tube that spans across the vehicle's side window diagonally and provides head protection. A third type of side air bag is a thorax or torso side air bag that can be installed in either the seat back or the vehicle door. The system provides protection for the torso but not for the head. The last type is a combination (also called "combo") air bag that incorporates both the head and thorax air bags into one unit. Typically, these air bags are installed in the seat back. The thorax bag inflates initially and then the gas moves into the head portion of the combo bag. While side air bag systems can be installed in a vehicle

[4] According to Samaha and Elliott (in a report titled "NHTSA Side Impact Research: Motivation for Upgraded Test Procedure," Samaha, Elliott, ESV, USA 492, Table 18), when the fatal NASS/CDS cases are considered, a small size seriously injured occupant is twice as likely to die in a narrow object crash than the large size occupants and less likely to die in a crash with a passenger car.

separately, we believe that most manufacturers would use both torso and head protection by either supplying a combo bag, a torso bag with a curtain, or a torso bag with an ITS.

Side impact sensors detect when a side impact crash occurs and deploy the air bag(s). Through its testing, the agency has found that in the oblique pole test with the pole aimed at the head of the 5th percentile dummy seated full forward, that not every vehicle's side impact sensors detected the collision. Thus, in some cases, the side air bag(s) have not deployed. For this analysis the agency estimates costs under two assumptions, either that two sensors or four sensors per vehicle will be used. The reason that a manufacturer might choose four sensors is to better sense narrow object (poles and trees) strikes for the front seat and the rear seat when a window curtain head restraint it uses covers both the front and rear seat.

We are going to analyze three of the countermeasure systems being currently used in the fleet. A large number of manufacturers use (1) the combination head/thorax air bag with two-sensor system, and (2) the window curtain and side thorax air bag with two-sensor system. Only a few vehicles have (3) a window curtain, side thorax 4-sensor air bag system. However, this 4 sensor system could become more prevalent if this final rule, in particular testing with an oblique pole test with the 5th percentile female dummy, forces manufacturers to move their sensor from the B-pillar forward on the side rail and as a consequence they can no longer provide protection from a pole/tree impact near a rear seated occupant. The oblique pole procedure is only for front seat protection, thus, a 4 sensor system to help protect rear seat occupants would be strictly voluntary.

<u>The combination head/thorax side air bag in the front seat, 2 sensor system:</u>

This is the lowest cost option analyzed that manufacturers could use to meet this requirement.

The countermeasure for this approach will be wider front seat combination head/thorax air bags than are currently provided. The system includes two sensors per vehicle, one sensor per side, possibly on the side rail near the front door. If a make/model already has window curtains as optional or standard equipment, we assume they will remain, but be made wider. The requirement is only for front seat protection, thus, there is no need for a combination head/thorax air bag for the rear seat or for 4 sensors for combination bags to cover the rear seat.

Benefits include near-side front seat occupants in vehicle-to-vehicle and pole/tree impacts and far-side unbelted occupants. We have found no benefits for far-side belted occupants.

<u>The window curtain for the front and rear seat, side thorax air bag for the front seat, 2 sensor system:</u>

The countermeasure for this approach will be one window curtain covering both the front and second seat and separate thorax side air bags for the front seat only. The system includes two sensors per vehicle, one sensor per side, possibly on the (floor) side rail near the front door. Benefits include near-side front seat occupants in vehicle-to-vehicle and pole/tree impacts, and far-side unbelted occupants. Rear seat occupant benefits for the head include near-side occupants in vehicle-to-vehicle impacts and far-side unbelted occupants in vehicle-to-vehicle impacts. However, no benefits are included for pole/tree impacts for the rear seat occupants because we assume that narrow object impacts in the rear area may not be sensed by the forward sensor.

<u>The window curtain for the front and rear seat, side thorax air bag for the front seat, 4 sensor system:</u>

The countermeasure for this approach will be one window curtain for both the front and second row seats and a separate thorax side air bag for the front seat only. The system includes 4-sensors per vehicle, 2 on the side rail near the front door and 2 on the (floor) side rail near the rear door. A few manufacturers have a 4-sensor system currently.

Benefits include front seat near-side occupants in vehicle-to-vehicle and pole/tree impacts, and far-side unbelted occupants. Rear seat occupant benefits for the head include near-side occupants in vehicle-to-vehicle and pole/tree impacts, and far-side unbelted occupants.

Other countermeasures used by very few manufacturers, like the ITS head air bag and side thorax air bags for rear seat occupants were not analyzed. The ITS head air bag could be used to meet this requirement. The ITS head air bag is believed to have essentially the same costs and benefits as a window curtain system except that it does not have the same ejection reduction protection potential as a window curtain. The agency is considering a rulemaking to protect front and rear seat occupants from ejection in rollover crashes. We believe that most vehicle manufacturers would use window curtain air bags to protect occupants from complete and partial ejection in rollover crashes. This is one of the reasons that we are not requiring a second pole test that would be aimed at rear seat occupants. We believe a window curtain will provide protection for rear seat occupants, and that we can assure rear seat coverage with the ejection mitigation rulemaking.

In summary, the three countermeasure systems we are analyzing in this FRIA are:

Countermeasure System	**2 Sensors**	**4 Sensors**
Combination head/thorax side air bags – front seat	X	
Window curtain covers front and rear seat for the head and separate front seat only thorax side air bag	X	X

Technical Feasibility

The agency has performed a series of pole tests including the optional pole test specified in FMVSS No. 201. The test results show that the majority of currently available head and side air bags would meet the oblique pole test with the 50th percentile test dummy. However, the results from the full forward seated 5th percentile pole tests show that not all systems picked up this narrow object strike forward on the door. We suspect that the current sensor installed near the B-pillar will have to be moved forward to the side rail under the front door to deploy the air bag in the oblique 5th percentile female test. If a manufacturer has to move this sensor forward, it may want to add an additional sensor near the C-pillar to pick up impacts near the rear seat occupant and provide real world benefits to rear seat occupants, or for the sensor system to be redesigned. As discussed above, we have estimated costs under both assumptions, that two sensors and four sensors per vehicle could be used with a window curtain system.

Some of the window curtains we tested were not wide enough to provide the protection desired in the oblique impacts, particularly when the 5^{th} percentile female dummy was seated full forward in the oblique impact. We did not find any thorax bags or combination bags that did not meet the criteria because they weren't wide enough. However, we only tested 3 combination air bags and if a side air bag was minimally designed to meet a perpendicular test, then it would need to be wider to meet an oblique test. In this analysis, we assume that wider thorax air bags, wider combination air bags, and wider window curtains will be needed to provide protection in the test conditions. This is a conservative assumption, which raises costs to some extent (see Chapter VI for information on costs). The agency has not designed and produced such systems, however, it appears to be well within the engineering capability of the air bag suppliers and some vehicles already meet the requirements. The only concern we had was in making a wider combination air bag, which would require more gas to be put into the air bag, and what effect this might have on meeting the voluntary Technical Working Group (TWG) out-of-position testing for side air bags. If this becomes a concern, a manufacturer might then choose the window curtain thorax air bag system. We are not concerned about the ability of a wider thorax air bag meeting the voluntary TWG testing, since a wider thorax air bag would be smaller than combination air bags, which are passing the TWG testing.[5]

Regarding the MDB test, a total of 17 tests were conducted, nine (9) of them were with the ES-2re and the other eight (8) tests were with the SID-IIs, according to the FMVSS No. 214 MDB test procedures. The results show that all but one vehicle met the requirements when tested with the ES-2re dummy and its associated injury criteria. The results also show that the 2002 Chevrolet Impala in the rear seating position did not meet the abdominal force criterion. An examination of the passenger compartment interior revealed that the rear armrest design and location maybe the problem.[6] During a MDB side impact test, the protruded armrest would contact the abdominal area of a 50th percent male dummy that is placed in the rear outboard seating position on the struck side. A severe abdominal impact is likely to create an excessively large force resulting in injuries. It seems evident that the armrest of the Chevrolet Impala can be modified to alleviate this situation. A common modification is to extend the lower edge of the armrest to completely cover the lower torso of the test dummy. This design has already been used in many vehicles, including the 2001 Ford Focus. However, this particular modification may reduce the rear seat width by a small amount. The MDB tests with the SID-II show that three vehicles failed to meet the pelvis force requirement: one in the front and the other two in the rear. In addition, three out of eight vehicles show relatively high chest

[5] We do not consider a reduction in benefits resulting from children being out-of-position (OOP) from thorax air bags. Testing child dummies OOP has shown no problem for HPS systems mounted on the roof rail (window curtain and the ITS). In addition, the automobile manufacturers have voluntary standards for OOP testing and to date the agency is not aware of any serious OOP child injuries due to side air bags.

[6] The armrest is made of foam material and its main portion is approximately 75 mm (3 inch) in width, 75 mm in height, and 250 mm (12 inch) in length. The lower edge of the armrest is approximately 100 mm (4 inch) <u>above</u> the seat surface. In addition to the high abdominal force, a chest deflection of 45.6 mm was measured with the front ES-2re dummy.

deflection levels: 49 mm, 47 mm and 45 mm for the VW Jetta, Saturn Ion and Ford Five-Hundred, respectively. The results indicate that small stature occupants in the rear seating positions would be more vulnerable to serious chest injuries, when compared to occupants represented by a 50th percentile male test dummy.

III. INJURY CRITERIA

This section contains a description of the Injury Criteria and Probability of Injury at a given injury level. This section describes how the dummy head, chest, abdomen and pelvis responses measured by the test dummies relate to human tolerance/injury risk potential and the associated probability of injury.

A. Summary of NHTSA's Injury Criteria.

Head – A maximum HIC_{36} of 1,000 is required for the 50th percentile male ES-2re test dummy, as well as for the 5^{th} percentile female dummy. HIC was developed from hard rigid surface cadaver head drop data and was designed to minimize skull fracture and brain injury due to head contact. The predicted distribution of head injury incidence was derived from the following injury risk probability formula (Prasad and Mertz estimated head injury risk as a function of HIC):

AIS 1+:	$[1 + \exp((1.54 + 200/HIC) - 0.0065 \times HIC)]^{-1}$
AIS 2+:	$[1 + \exp((2.49 + 200/HIC) - 0.00483 \times HIC)]^{-1}$
AIS 3+:	$[1 + \exp((3.39 + 200/HIC) - 0.00372 \times HIC)]^{-1}$
AIS 4+:	$[1 + \exp((4.9 + 200/HIC) - 0.00351 \times HIC)]^{-1}$
AIS 5+:	$[1 + \exp((7.82 + 200/HIC) - 0.00429 \times HIC)]^{-1}$
Fatal:	$[1 + \exp((12.24 + 200/HIC) - 0.00565 \times HIC)]^{-1}$

For each HIC interval, the formula for each AIS level was subtracted from the preceding AIS level to determine the probability of injury for that AIS and HIC level.

Chest – There are two separate injury criteria for chest: chest deflection for the ES-2re, and lower spine acceleration for the SID-IIs. For the oblique pole test, the agency is requiring injury criteria for chest deflection of 44 mm for the ES-2re 50th percentile male test dummy. For the SID-IIs 5th percentile female test dummy, the agency is requiring a lower spine acceleration of 82 g.

Abdomen – For the pole test, the agency is requiring an abdominal force limit of 2.5 kN for the ES-2re 50th percentile test dummy.

Pelvis – For the pole test, the agency is requiring a pelvic force limit of 6.0 kN for the ES-2re 50th percentile male test dummy and 5,525 N for the SID-IIs 5th percentile female test dummy.

B. Injury Criteria for Test Dummies Used

(1) ES-2re Injury Criteria

The performance requirements in FMVSS No. 214 for a vehicle tested with an ES-2re dummy are based upon the injury criteria discussed below. In assessing the suitability of a dummy for side impact testing, it is necessary to consider its injury assessment capabilities relative to human body regions at risk in the real world crash environment. Crash data indicate that the performance requirements in FMVSS No. 214 should protect not only an occupant's head, but also other body regions in the vehicle-to-pole test. Accordingly, injury criteria are being required for the head, thorax, abdomen, and pelvis.

While the ES-2 is an upgraded EuroSID-1 dummy, NHTSA determined that the ES-2 was so fundamentally different from the predecessor dummy that previously-generated

EuroSID-1 data should not be considered in analyzing the ES-2 and its associated injury criteria. The flat-topping and other problems of the EuroSID-1 made those earlier data of little value to researchers in analyzing the ES-2. Consequently, in developing the criteria discussed below, NHTSA limited its analysis to existing ES-2 data and our own research conducted with the ES-2re. Based upon our assessment of these dummies, we believe that the ES-2 (with rib extension modifications) is superior to the unmodified version. Accordingly, the agency is requiring use of the ES-2re.

Head: NHTSA is requiring a HIC limit of 1,000 (measured in a 36 millisecond time interval) when the ES-2re dummy is used in the 20 mph oblique vehicle-to-pole test. The HIC_{36} 1000 criterion is consistent with the optional pole test designed to afford head protection under FMVSS No. 201. This measure is also consistent with the requirement in the European side impact standard for the EuroSID-1. Thus, the HIC_{36} 1000 criterion provides a measure that has proven successful in the US and in Europe with which the agency already has experience.

Thorax (Chest): NHTSA is requiring a chest deflection criterion to measure thoracic injury when using the ES-2re. Chest deflection may be no greater than 44 mm (reflecting an approximate 50 percent risk of an AIS 3+ injury).

NHTSA reanalyzed the Eppinger data set (see footnote immediately above) and the injury risk curve versus TTI(d) and estimated that a rib deflection of 44 mm for the ES-2re would be approximately equivalent to a TTI(d) of 85 g's for the SID. The 38 to 44 mm range correspond to a 40 to 50 percent risk of AIS 3+ injury. (Kuppa, Eppinger, McKoy, Nguyen and Pintar, “Development of a Side Impact Thoracic Injury Criteria and Its Application to the EuroSID-2 Dummy,” Stapp Car Crash Journal, Vol. 47, October 2003). The percent risk of injury corresponds to the risk of injury for a 45-year-old occupant. (Logistic regression analysis using cadaver injury and anthropometry information along with the ES-2 measurements indicate that the age of the subject at the time of death had a significant influence on the injury outcome ($p<0.05$).)

Although the NPRM proposed to limit lower spine acceleration in the pole and MDB tests of the ES-2re dummy, the final rule does not adopt the lower spine acceleration limit for the ES-2re in this rulemaking. In the oblique pole tests conducted in our vehicle test program, the ES-2re’s lower spine acceleration readings were relatively consistent with the dummy’s rib deflection readings. Because of this consistency, we conclude that, in the oblique pole and MDB tests, the lower spine acceleration criterion is unnecessary for the ES-2re. The dummy’s rib deflection measurements alone will detect injurious loading of the thorax.

The chest injury probability equations and curves for AIS 3+ and 4+ injuries are shown in Table III-1 and Figure III-1.

Table III-1. Chest Injury Probability Curves for ES-2re

$$p(AIS3+) = \frac{1}{1+e^{(2.0975-0.0482*peak\ \ rib.\ \ defl.)}}$$

$$p(AIS4+) = \frac{1}{1+e^{(3.4335-0.0482*peak\ \ rib.\ \ defl.)}}$$

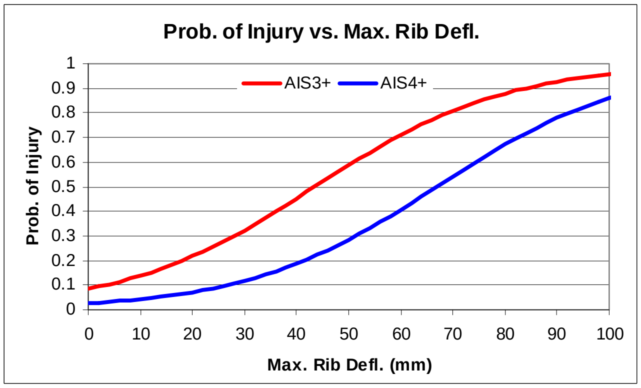


Figure III-1. Probability of AIS 3+ and AIS 4+ injury as a function of maximum ES2 rib deflection

Abdomen: The ES-2re dummy offers abdominal injury assessment capability, a feature that is not incorporated in the SID-H3 dummy. The agency is requiring an abdominal injury criterion of 2.5 kN (50 percent risk of AIS3+ injuries). The abdominal injury criterion was developed using cadaver drop test data from Walfisch, et al. (1980)[7]. Analysis of this data indicated that applied force was the best predictor of abdominal injury. An applied force of 2.5 kN corresponds to a 33 percent risk of AIS 3+ injury. The MCW sled test data indicated that the applied abdominal force on the cadavers was approximately equal to the total abdominal force in the ES-2re dummy under similar test conditions. Therefore, an ES-2re abdominal force of 2.5 kN corresponds to a 33 percent risk of AIS 3+ injury.

[7] Walfisch, G., Fayon, C., Terriere, J., et al., "Designing of a Dummy's Abdomen for Detecting Injuries in Side Impact Collisions," 5th International IRCOBI Conference, 1980.

This abdominal capability of the ES-2re is a potentially significant advantage over the SID-H3 dummy, and its use in FMVSS No. 214 may reduce the number of abdominal injuries to the driving population. In a NASS study of side impact crashes, it was estimated that between 8 percent and 18 percent of all AIS 3+ injuries are to the abdomen of restrained drivers.[8] The dummy in current FMVSS No. 214 does not have these detection capabilities, thus leaving a gap in the control of injury outcomes for side crashes.

As background information, Walfisch et al. (1980) conducted 11 cadaver drop tests on either rigid or padded armrests from a height of 1 or 2 meters. Three of the test data were found as invalid. The remaining eight tests and the pendulum impact test from Viano (1980) were analyzed for the development of the Eurosid abdomen. The age of the cadaver at the time of death ranged between 45 and 68 years; age was found to have a poor association with injury outcome in the Walfisch data set. Measured applied force was found to be a good predictor of injury compared to other measures. There are only two observations with abdominal injuries in the Viano data set and so the AIS 4+ risk curve generated using it may not be as reliable. The 25% and 50% risk of AIS 3+ abdominal injuries from the Walfisch data set is at applied force of 2.3 kN and 2.8 kN. The 25% and 50% risk of AIS 4+ abdominal injuries from the Walfisch data set is at an applied force of 3.8 kN and 4.4 kN. The injury risk curves developed using the drop test

[8] Samaha, R.S., Elliot, D., “NHTSA Side Impact Research: Motivation for Upgraded Test Procedures,” Proceedings of the 18th Enhanced Safety of Vehicles (ESV) Conference (2003).

data can be used with ES-2re total abdominal force measurements[9] and are presented in Figure III-2.

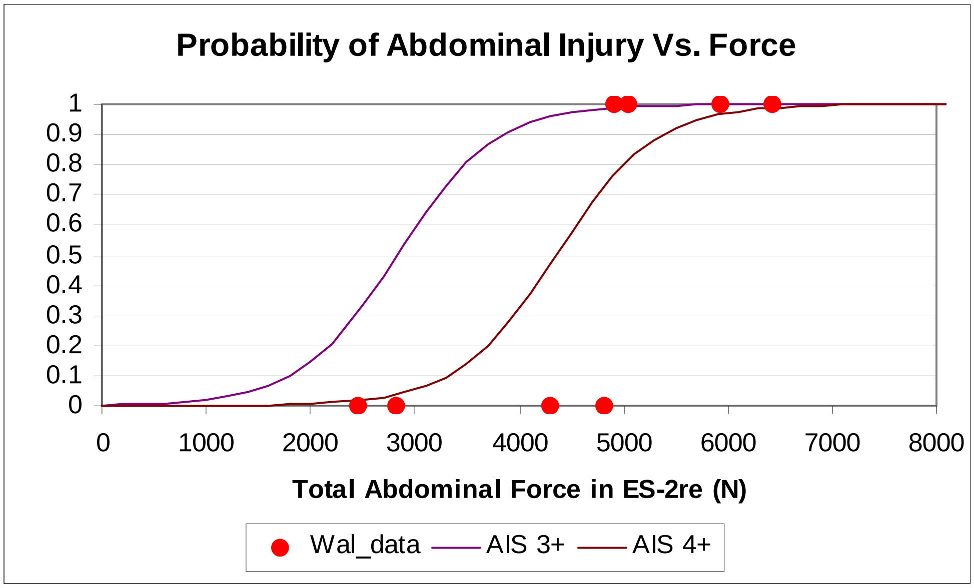


Figure III-2. Risk of abdominal injury as a function of total abdominal force measured in the ES-2re dummy

The ES-2re dummy has three (3) load cells in the abdomen – anterior, middle and posterior abdomen load cells. The sum of the forces measured in these three load cells is an estimation of the total load in the abdomen. Injury probability as a function of peak abdomen force for the test dummies are shown below:

Table III-2. Abdomen Injury Probability Curves for ES-2re

$$p(AIS3+) = \frac{1}{1+e^{6.04044-0.002133*F}}$$

$$p(AIS4+) = \frac{1}{1+e^{9.282-0.002133*F)}}$$

[9] For additional discussion, see "Injury Criteria for Side Impacts Dummies," May, 2004, Shashi Kuppa, National Transportation Biomechanics Research Center, NHTSA.

Pelvis: For the ES-2re, NHTSA is requiring a pelvic force performance limit of not greater than 6.0 kN (25 percent risk of AIS 3+). The ES-2re has two pelvic measurement capabilities. First, the ES-2re has instrumentation to measure pelvic acceleration, as does the SID-H3 dummy. However, unlike the SID-H3, the ES-2re is also capable of measuring the force (load) at the pubic symphysis, which is the region of the pelvis where the majority of injuries occur. A field accident analysis of 219 occupants by Guillemot et al. (1998) showed that the most common injury to the pelvis was fracture of the pubic rami (pelvic ring disruption).[10] Pubic rami fractures are the first to occur because it is the weakest link in the pelvis. The criterion in those programs is 6.0 kN. The equations of the injury risk curves are shown in Table III-3.

Table III-3
Pelvic Injury Probability Curves for ES-2re

$$P(AIS\ 2+) = 1/(1 + e^{6.403 - 0.00163*F})$$

$$P(AIS\ 3+) = 1/(1 + e^{7.5969 - 0.0011*F})$$

(3) SID-IIs Injury Criteria

Injury criteria are being required for the head, thorax, and pelvis. A complete discussion of these injury criteria and supporting data can be found in NHTSA's research paper, "Injury Criteria Development for Side Impact Dummy[11]," which has been placed in the Docket for the FMVSS No. 214 Final Rule.

[10] Guillemot H., Besnault B., Robin, S., et al., "Pelvic Injuries In Side Impact Collisions: A Field Accident Analysis And Dynamic Tests On Isolated Pelvic Bones," Proceedings of the ESV Conference, Windsor, 1998.
[11] See the technical document "Injury Criteria for Side Impact Dummies," May 2004, Shashi Kuppa, National Transportation Biomechanics Research Center, National Highway Traffic Safety Administration.

Head: The head injury criterion (HIC) shall not exceed 1000 in 36 ms, when calculated with the following equation:

$$HIC = \left[\frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} a dt \right]^{2.5} (t_2 - t_1)$$

Thorax (Chest): NHTSA is requiring that the resultant lower spine acceleration must be no greater than 82 times the acceleration due to gravity (82 g's). The resultant lower spine acceleration is a measure of loading severity to the thorax. For the SID-IIs test dummy, resultant spine acceleration will not be limited to lateral acceleration. In vehicle crashes, loading can be in various directions. Therefore, NHTSA believes that to account for overall loading, resultant accelerations should be considered rather than lateral acceleration alone. However, since lower spine acceleration may not have a causal relationship to injury outcome, a low 5 percent false positive rate (cases when the value indicates that there is an injury when injury has not occurred) was used to determine its threshold limit.

NHTSA selected the criterion based upon a series of 42 side impact sled tests using fully instrumented human cadaveric subjects, previously discussed, conducted at the MCW as well as sled tests conducted with the SID-IIs dummy under identical impact conditions as the cadaveric sled tests. The agency believes that the age of the subject involved in a side impact affects injury outcome. Subject age in the MCW sled test data was found to have significant influence on injury outcome and so was included in the injury models. The resulting thoracic injury risk curves were normalized to the average age of the injured population in a side impact crash that is represented by the SID-IIs dummy. The average age of AIS 3+ injured occupants less than 1,626 mm (5'4") involved in side impact crashes with no rollovers or ejections was 56 years based on NASS-CDS files for the year 1993-2001. Therefore, thoracic injury risk curves were normalized to the average occupant age of 56 years.

The injury probability equations are shown in Table III-6.

Table III-6a
Chest Injury Probability Curves for SID-IIs
Based on Peak rib Deflection

$$p(AIS3+) = \frac{1}{1+e^{(5.8627-0.15498*peak\ \ rib.\ \ defl.)}}$$

$$p(AIS4+) = \frac{1}{1+e^{(7.7998-0.15498*peak\ \ rib.\ \ defl.)}}$$

Table III-6b
Chest Injury Probability Curves for SID-IIs
Based on Lower Spine Acceleration

$$p(AIS3+) = \frac{1}{1+e^{(1.364-0.0212*\max lowerSpineAccel.)}}$$

$$p(AIS4+) = \frac{1}{1+e^{(2.4634-0.021*\max lowerSpineAccel.)}}$$

Pelvis: To obtain the injury risk curve for a small female, the agency normalized the pelvic force data from the Bouquet pelvic impact tests to that of a small female weighing 48 kg, as indicated in the technical document, "Injury Criteria for Side Impact Dummies," supra. In addition, the risk curve was adjusted to that for a 56 year old. Data submitted by the Alliance in a September 2, 2005 comment regarding with the relevant cadaver tests from Bouquet suggested that the sum of acetabular and iliac force of the SID-IIs is approximately 1.21 times that of the applied cadaver force under similar impact conditions of the Bouquet test setup. Accordingly, rather than the proposed pelvic force limit of 5,100 N, the final rule has adopted a pelvic force IARV limit of 5,525 N, which corresponds to a 25% risk of AIS 2+ injury using also a factor for reduced bone strength in older women (0.88). The risk curves for AIS 3+ and AIS 4+ are shown in Table III-7.

Table III-7
Pelvic Injury Probability Curves for SID-IIs

$$p(AIS2+) = \frac{1}{1 + e^{(6.3055 - 0.00094 * (iliac + acetab.\ force))}}$$

IV. TEST DATA AND ANALYSIS OF POLE TEST DATA

This chapter presents test data available to the agency on the oblique pole test.

As part of the agency's research effort, a series of oblique pole and FMVSS No. 201 optional pole tests were performed with a 5th and 50th percentile test dummies. (See Section IV of the final rule preamble, and Appendix C of the final rule preamble, respectively.) The oblique pole test is similar to the FMVSS No. 201 optional pole test except for modifications relating to the angle, speed, the test dummies used in the test and seating procedure. For the 50th test dummy, the seating procedure specified in FMVSS No. 214 was used.

A. Pole. The oblique pole has the same specifications as the pole used in the FMVSS No. 201-optional pole test. It is a vertical metal structure beginning not more than 102 mm (4 inches) above the lowest point of the tires on the striking side of the test vehicle when the vehicle is loaded as specified in the standard and extending above the highest point of the roof of the test vehicle. The pole is 254 mm (10 inches) ± 3 mm in diameter and set off from any mounting surface such as a barrier or other structure, so that a test vehicle would not contact such a mount or support at any time within 100 milliseconds of initiation of vehicle-to-pole impact.

In the vehicle-to-pole test, the centerline of the rigid pole is aligned with an impact reference line drawn on the struck side of the vehicle. In the procedure for the oblique pole test, the impact reference line is in a vertical plane that passes through the cg of the dummy's head in a direction that is 75 degrees from the vehicle's longitudinal centerline. In the oblique pole test, the dummy and the vehicle seat are positioned as in FMVSS No. 214 (i.e., mid-track). The initial pole-to-vehicle contact must occur within an area bounded by two transverse vertical planes located 38 mm (1.5 inches) forward and aft of the impact reference line.

Regarding the repeatability of the oblique pole test, the agency conducted three repeatability tests using the 1999 Nissan Maxima. The test results show that the points of first contact between the pole and vehicle exterior were between 2 mm and 15 mm rearward of the impact reference line. In all three tests, the head of the ES-2 dummy contacted the pole, with the seat in the mid-track position. In addition, the agency conducted two additional oblique pole tests using 1999 Volvo S-80 cars. Test results show that the contact points were 5 mm and 32 mm rearward of the impact reference line. One test was conducted with a SID-H3 dummy and another with an ES-2 dummy. (While the head of both dummies contacted the pole, the SID-H3 head rotated off the air curtain directly into the pole resulting in a very high HIC score.) In conclusion, in all five tests, the contact points were within the 38 mm (1.5 inches) tolerance limit specified in the FMVSS No. 201 procedure and in the final rule, and the dummy's head contacted the pole directly in tests without a head protection system (HPS) or indirectly (including head rotating into the pole) in tests with a HPS system.

1. Impact Speed

The vehicles were tested at an impact speed of 20 mph for the oblique pole tests.

2. Angle of Impact

In the oblique pole test, a vehicle is propelled into the pole with an impact angle of 75-degrees rather than the 90-degrees specified in FMVSS No. 201. An impact reference line is drawn on the intersection of the vehicle's exterior and a vertical plane passing through the head center of gravity (CG) of the seating dummy at an angle of 75 degrees from the vehicle's longitudinal centerline (see Figure IV-1). The vehicle is aligned with the center line of the rigid pole so that, when the pole contacts the vehicle, the vertical center line of the pole is within an area on the vehicle area bounded by two transverse vertical planes 38 mm (1.5 inches) forward and aft of the impact reference line. The test vehicle is propelled sideways into the pole. Its line of forward motion forms an angle of 75 degrees (±3 degrees) measured from the vehicle's longitudinal axis in the counterclockwise direction. The oblique pole test was developed by NHTSA based on an analysis of the safety need[12] to incorporate an oblique impact in a side impact protection standard.

3. Seat Positioning and Impact Reference Line

(1) 50th percentile male dummies. In the oblique pole test, an impact reference line is placed on the exterior of the vehicle positioned relative to the center of gravity of the head of the dummy seated in the front outboard designed seating position, with the 50th

[12] According to the 2000 – 2004 NASS CDS annualized counts for front outboard MAIS 1+ occupant injuries, 36% of the injuries occurred at 3 and 9 o'clock positions (i.e., perpendicular) and 56% of the injuries occurred at 2 and 10 o'clock positions (i.e., oblique).

percentile male test dummy and the vehicle seat positioned as in the FMVSS No. 214 seating procedure.

(2) 5th percentile female dummy. Procedures for determining the impact reference line for the test using the 5th percentile female dummy is similar to that discussed above for determining the line when using the male dummy. However, dummy positioning would differ, in that the female dummy would be positioned in the vehicle seating position in the manner described in FMVSS No. 208 for positioning the 5th percentile female test dummy for testing of a vehicle's frontal occupant protection system. In other words, the dummy would be seated fully forward.

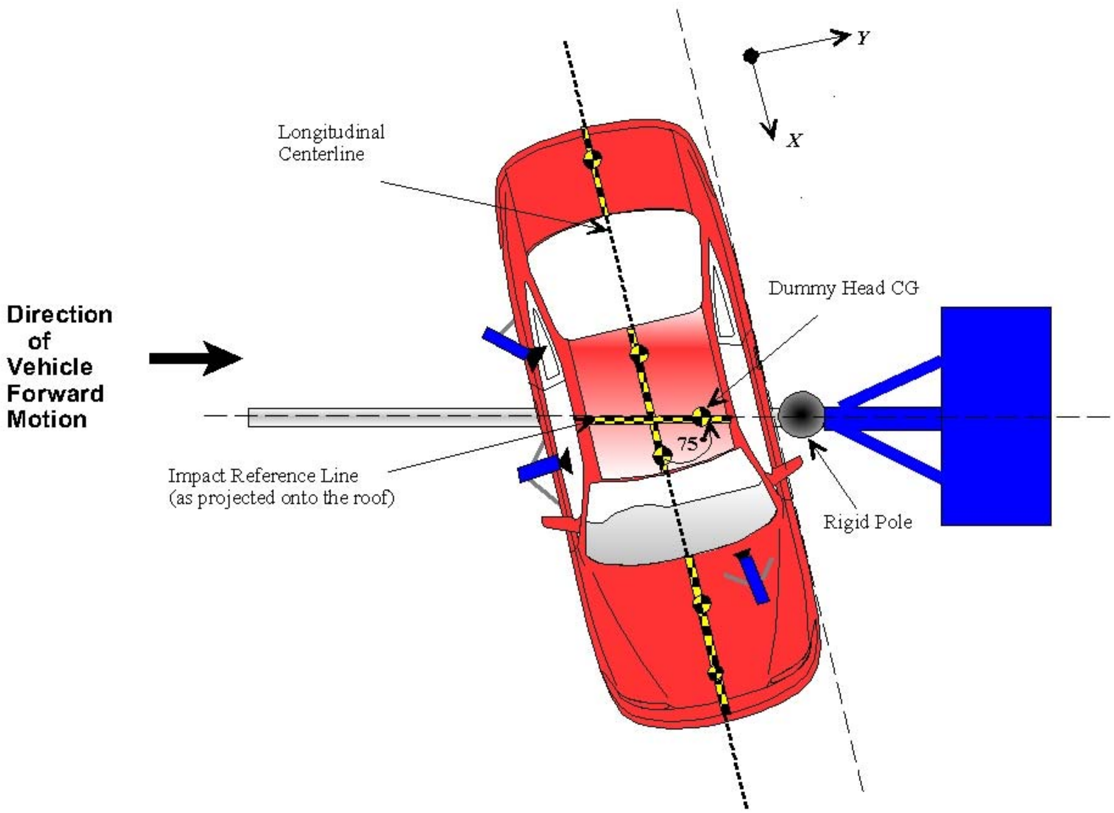


Figure IV-1. Illustration of Oblique Pole Impact

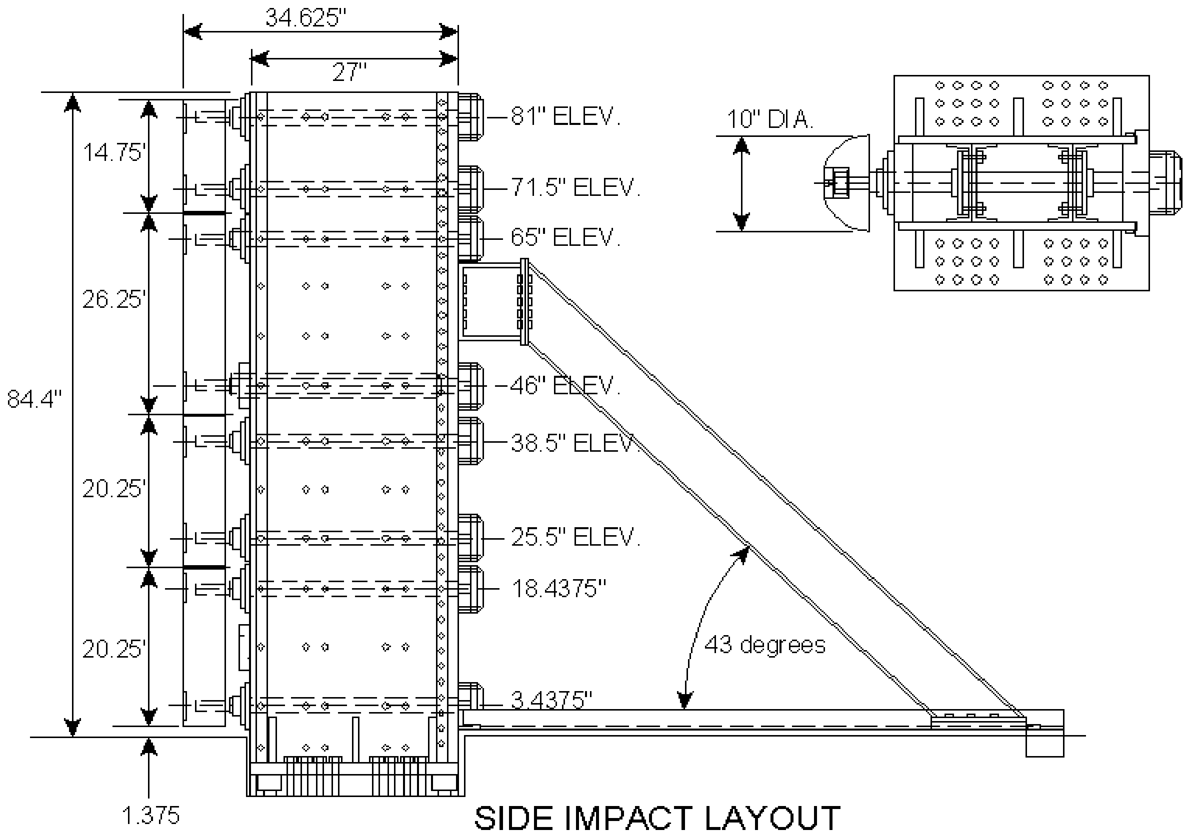


Figure IV-2. Dimension and Construction of Pole

B. Test Dummies

1. <u>ES-2re, 50th Percentile Male Crash Test Dummy</u>

The ES-2 dummy is considerably more biofidelic than SID and offers more injury measurement capabilities than the present side impact dummy.

(1) General. The ES-2 dummy evolved from the EuroSID and EuroSID-1 (ES-1) dummies. EuroSID existed when the agency adopted the dynamic moving deformable

barrier test into FMVSS No. 214 in 1990. However, when the agency examined the dummy, NHTSA determined that EuroSID suffered from a number of technical problems involving "flat topping,"[13] biofidelity, reproducibility of results, and durability. Because of these limitations, NHTSA decided against adopting EuroSID and instead adopted SID as the test device used in the dynamic FMVSS No. 214 test. Flat topping was a matter of concern, especially at high levels of deflection, because they are an indication that the dummy's rib deflection mechanism is binding, and consequently, the dummy's thorax is not responding correctly to the load from the intruding side structure.

ES-1 and ES-2 are the first and the second generations, respectively, of the EuroSID dummies. ES-2 was designed to overcome the concerns raised by NHTSA and users of the dummy worldwide. Beyond flat topping, concerns had been raised about the projecting back plate of the dummy grabbing into the seat back, upper femur contact with the pubic load cell hardware, binding in the shoulder assembly resulting in limited shoulder rotation, and spikes in the pubic symphysis load measurements associated with knee-to-knee contact. To address these concerns, the dummy manufacturer installed hardware upgrades in the ES-2, including an improved rib guide system in the thorax, a curved and narrower back plate, a new attachment in the pelvis to increase the range of upper leg abduction and inclusion of rubber buffers, a high mass flesh system in the legs, and beveled edges in the shoulder assembly.

[13] The preamble to NHTSA's final rule adopting its current side impact dummy (SID) noted that the agency found that the EuroSID dummy had problems with flat topping. The agency stated, "[o]ne of the problems discovered in NHTSA's EuroSID sled tests was that the ribs were bottoming out, which may have invalidated the V*C measurements being made. This condition was characterized by a flat spot on the displacement-time history curve, while the acceleration-time history curve showed an increase with time until the peak g was reached. Although considerable attempts were made to correlate V*C and TTI(d), the deflection data collected continue to be questionable." 55 FR 45757, 45765 (October 30, 1990).

Nonetheless, the ES-2's back plate continued to grab the seat back in some side impacts conducted by industry and NHTSA, despite the dummy manufacturer's initial efforts to address the problem. NHTSA and the dummy manufacturer were able to solve the problem by installing a set of six needle bearings to the back plate (two bearings per rib) plus a Teflon cover. According to NHTSA's test data, these "rib extensions" reduce to a great extent the back plate grabbing force that had the effect of lowering rib deflection responses in tests. The rib extensions also do not appear to affect the dummy's rib deflection responses in tests in which back plate grabbing did not occur. The newest revision is the ES-2re.

The ES-2re head design is the same as that of the Hybrid III 50th percentile male dummy. It consists of an aluminum shell covered by a pliable vinyl skin. The interior of the shell is a cavity accommodating triaxial accelerometers and ballast.

The ES-2re thorax consists of a rigid thoracic spine box and three identical rib modules. The rib module consists of a steel rib covered by a flesh-simulating polyurethane foam, a piston-cylinder assembly linking the rib and spine box together, a hydraulic damper, and a stiff damping spring. A displacement transducer is mounted on the front surface of the cylinder and connected to the inside of the rib.[14] The instrumentation locations for the ES-2re are shown in Figure IV-3.

[14] Details of the rib extension design are found in Attachment IV, "Design Development and Evaluation of the ES-2re Side Crash Test Dummy," August 2003. Docket NHTSA-18864

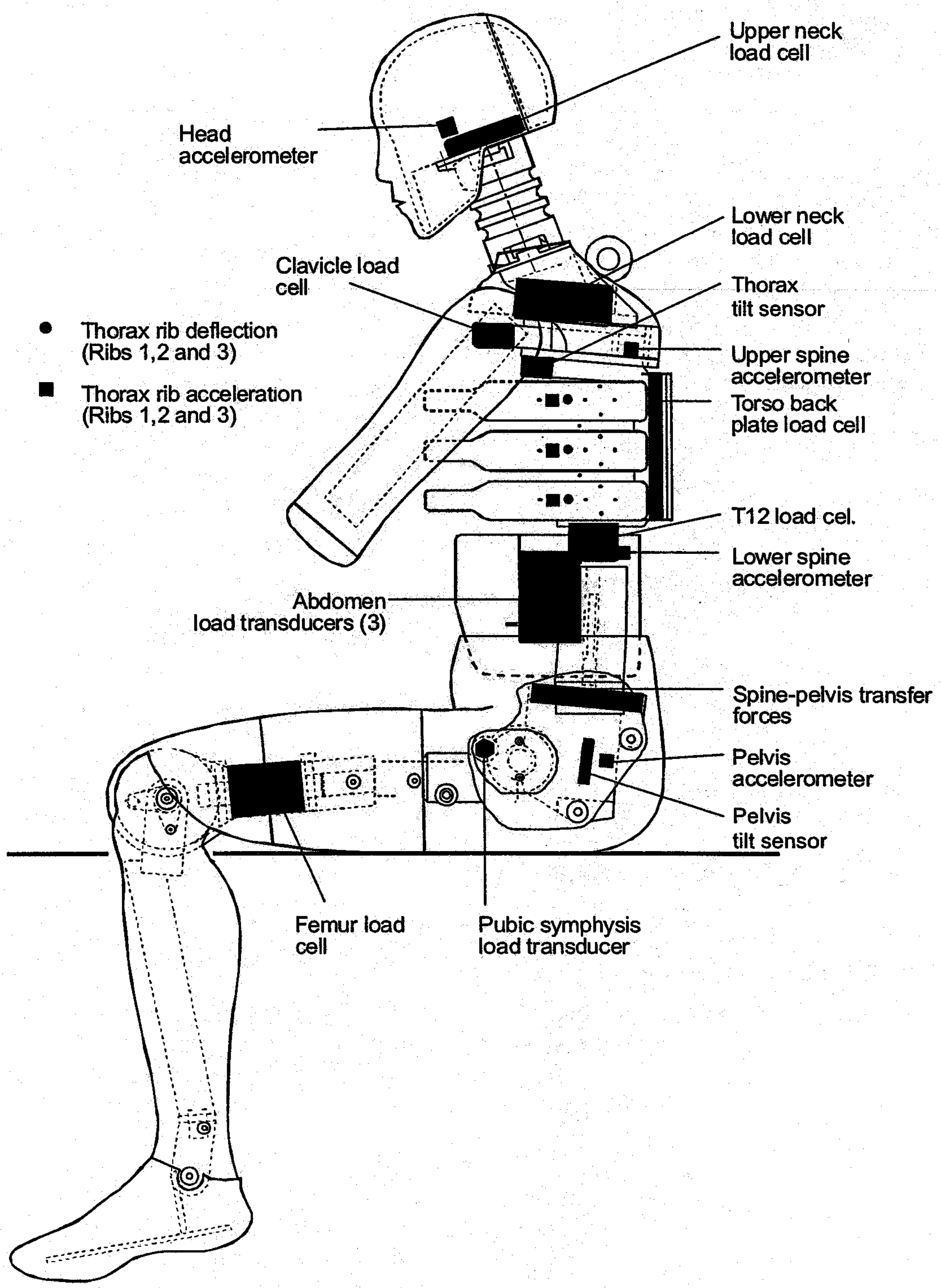


Figure IV-3. Instrumentation Location in ES-2

2. 5th Percentile Female Test Dummy

The test dummy represents a 5th percentile female with extensive instrumentation that can be used to assess the type and magnitude of side impact forces on small-stature occupants. (This dummy is commonly called "SID-IIs Build Level D" dummy.) The dummy was developed for the purpose of assessing the performance of side air bags in side impact tests. It has a mass of 43.9 kg (96.78 pounds) and a seated height of 787 mm (31.0 inches). Based on its height and mass, it is also equivalent to an average 12-13 year old adolescent. The dummy is capable of measuring forces to the head, neck, shoulder, thorax, abdomen and pelvis body regions and measures compression of the thoracic region.[15]

(1) General. The new dummy was named SID-IIs indicating "SID" as side impact dummy, "II" as second generation, and "s" as small. The dummy was extensively tested in the late 1990s and in early 2000 in full-scale vehicle crash tests conducted by Transport Canada with some NHTSA financial support, and to a limited extent by automobile manufacturers and suppliers. NHTSA began an extensive laboratory evaluation of the dummy in 2000.

C. Pole Test Results

The agency has conducted a series of pole tests, and the results are tabulated in the following sections for each test dummy used. (Note that the agency performed the pole

[15] IIHS began evaluating vehicles in a side impact consumer information program in June 2003 using the SID-IIs (Build "C" version) in a moving deformable barrier test. Measures are recorded from the dummy's head, neck, chest, abdomen, pelvis and leg.

tests at 18 mph and 20 mph with different types of test dummies. The results from the ES-2re and the SID-IIs Build D were used for the analysis, unless otherwise specified.)

ES-2re test results: A total of three vehicles were tested as a baseline in the pole test with the ES-2re. The baseline tests have no head air bag countermeasures. The seating procedure specified in FMVSS No. 201 optional pole test was used for the 50th percentile male test dummy in these vehicles. The results are shown in Table IV-1.

Table IV-1
Baseline HIC With ES-2re
201-Seating Procedure

Vehicle	HIC
1999 Nissan Maximum, NHTSA #: V4285	11,983
1999 Nissan Maximum, NHTSA #: V4365	15,591
2001 Saturn, NHTSA #: V4246	15,152

Average	Std. Dev.	Max.	Min.
14,242	1,969	15,591	11,983

For vehicles with head/side air bags, a total of 15 vehicles were tested at a vehicle delta-V of 20 mph. The FMVSS No. 214 seating procedure was used for the 50th percentile male dummy positioning. The results are shown in Tables IV-2a and -2b.

Table IV-2a.
NHTSA Pole Test Results with ES-2re
(Oblique Pole at 20 mph, Test Dummy in 214 Seating Position)

Test Vehicle	**HPS Type**	**Head, HIC, Req:1,000**	**Chest Deflection, mm, Req: 44 mm.**[16]	**Abdomen Force, N, Req: 2.5 kN**	**Pubic Force N, Req: 6.0 kN**
1999 Volvo S80	AC+Th	329	**48.6** mm	1,547 N	1,127 N
2000 Saab 9-5	Combo	171	**49.4** mm	1,366 N	1,733 N
2004 Honda Accord	AC+Th	446	31 mm	1,397 N	2,463 N
2004 Toyota Camry	AC+Th	405	43.4 mm	1,165 N	1,849 N
2005 Toyota Corolla	AC+Th	473	**50** mm	1,178 N	3,041 N
2005 VW Jetta	AC+Th	652	36 mm	1,663 N	3,372 N
2005 Saab 9-3 Convertible	Combo	254	40 mm	841 N	2,914 N
2005 Ford Five-Hundred	AC (Canopy) +Th	422	35 mm	**3,020** N	2,133 N
2004/05 Toyota Sienna	AC+Th	667	**47** mm	1,751 N	2,127 N
2005 Subaru Forest	Combo	**2,053**	43 mm	1,377 N	2,291 N
2005 Honda CRV	AC+Th	639	**50** mm	929 N	903 N
2005 Chevy Colorado 4x2 Regular Cab w/Z85	AC	784	**46** mm	**2,655** N	3,373 N
2005 Ford Expedition	AC (Canopy)	689	26 mm	**6,973** N	2,575 N
2005 Beetle Convertible	Combo	315	37 mm	1,018 N	3,815
2005 Saturn Ion	AC	806	**50** mm	1,494 N	1,585 N

Note. Measurements that failed to meet the injury criteria are in bold.

[16] Scores higher than the injury criteria were not used for HPS characterization since they failed to meet the requirements, unless otherwise stated. Those that failed were, in essence, non-compliant vehicles (if there was a standard in place) and therefore would not be representative of the passing vehicle fleet and therefore are not used in the calculations.

Table IV-2b
Injury Measurement with ES-2re
Deployed Bag Performance **Meeting** the Requirements
With the 214-Seating Procedure
Oblique Pole Impact at 20 mph, with ES-2re 50th male dummy

Body Region	Injury Measurement	Average	Std. Dev.	Max.	min.
Head/face	HIC	504	202	806	171
Chest	Chest Deflection (mm)	38	5	43	31
	Lower Spine Acceleration (g)[1]	59	11	75	46
Abdomen	Abdominal Force (N)[1]	1,294	296	1,751	841
Pelvis	Pelvic Force (N)[2]	2,353	845	3,815	903

1. With thorax bags.
2. When the dummy met the requirements.

Head: The ES-2re test results in Table IV-2a show that head air bags are highly effective in preventing head injuries in vehicle-to-pole/tree side crashes. However, one out of fifteen air bags exceeded to meet the HIC criterion. Based on the measured HIC, we believe that the combo air bag (in the 2005 Subaru Forester) will be widened to restrain better the head in the oblique impact.

Head air bags that met the required HIC of 1,000, and side air bags that meet both the lower spine acceleration and chest deflection, were analyzed by air bag type, as shown in Tables IV-3 and -4

Table IV-3
Fleet Performance of Head Air Bag
Oblique Pole Test (at 20 mph)
(HIC less than 1,000, 214-Seating Procedure, ES-2re)

Head Bags	Performance (HIC)			
	Average	Std. Dev.	Max.	min.
Curtain	578	170	806	329
Combo	247	72	315	171
Curtain (Canopy[17])	556	N/A	689	422

[17] The curtain bag system is designed to deploy in certain side-impact collisions or rollovers.

Table IV-4
Fleet Performance of Side Air Bag
Oblique Pole Test (at 20 mph)
(Chest Deflection less than 44 mm, 214-Seating Procedure, ES-2re)

Side Bags	Deflection (mm)			
	Average	Std. Dev.	Max.	min.
Combo	40	3	43	37
Thorax	36	5	43	31

The pole test results with the 50th test dummy show that the average baseline HIC was 14,242 and the average deployed HIC was 504. When different types of head air bags are considered, the combination (combo) air bags produce an average HIC of 247, whereas the curtain and the canopy air bags produced 578 and 556 HIC scores, respectively.

Chest: The pole test results show that an average deflection of 38 mm was measured with deployed air bags. When the dummy met the lower spine acceleration requirement (82 g), an average lower spine acceleration of 59 g was measured with deployed thorax bags. As discussed above, several side air bags failed to meet the 44 mm deflection requirement (when measured with the 50th percentile test dummy positioned with the FMVSS No. 214 seating procedure), as shown in Table IV-5.

Table IV-5
Vehicles Failing to Meet 44 mm Deflection Requirement
214-Seating Procedure, ES-2re

Vehicle	Side Bag	Deflection (mm)
2005 Toyota Corolla	Torso	50
2004 /05 Toyota Sienna	Torso	47
2005 Honda CRV	Torso	50
2005 Chevy Colorado	no side bag	46
1999 Volvo S80	Torso	49
2000 Saab 9-5	Combo	49
2005 Saturn Ion	no side bag	50
	avg.	49

The chest deflection results in Table IV-5 show that vehicles that failed to meet the chest deflection limit of 44 mm produce an average deflection of 49 mm.

Table IV-6
Chest Deflection and Lower Spine Acceleration Measurements
ES-2re, 50^{th} Test Dummy
20 mph Oblique Pole with 214-Seating Procedure

	Average	Std. Dev.	Max.	min.
Chest Def w/o Th bag (mm)	41	13	50	26
Chest Def W/ Th bag (mm)*	38	5	43	31
Chest Def, if failed (mm)	49	2	50	46
Chest Def, if met Req. (mm)	36	6	43	26

According to the chest injury risk curve, there are 49% and 35% chances of AIS 3+ chest injuries, respectively, at these acceleration levels.

Abdomen: The pole test results show an average abdominal force of 3,707 N without thorax bags and, with thorax bags, the force decreased to 1,294 N. The results suggest that thorax bags are effective in reducing abdominal injuries in side crashes. During the "deployed air bag" tests, very high levels of abdominal force were measured with the 2005 Ford Five-Hundred (3,020 N) and the 2005 Ford Expedition (6,973 N). We suspect that these high abdominal forces were resulting from a door (armrest) intrusion to the dummy's abdominal area. The pole test data strongly indicate that the abdominal force requirement is needed to prevent a high load path to the abdominal area. The abdominal measurements are shown below:

Table IV-7
Abdominal Force Measurements
ES-2re, 50th Test Dummy
20 mph Oblique Pole

	Average	Std. Dev.	Max.	Min.
Abd Force W/o Th bag (N)	3,707	2,887	6,973	1,494
Abd Force W/ Th (N)	1,294	296	1,751	841
Abd Force, if failed (N)	4,216	2,395	6,973	2,655
Add Force, if met (N)	1,311	288	1,751	841

Pelvis: The pole test data show that the majority of vehicles would meet the pelvis requirement with an ample design/safety margin, whether vehicles are equipped with thorax bags or not. None of the vehicles failed the pelvis force requirement of 6,000 N. The results show that thorax bags would slightly reduce the force level, from 2,511 N to 2,314 N. Although thorax bags would provide some benefits, the benefits would be insignificant. (Since all vehicles met the required force level with and without air bags, the pelvic force measurements resulting from the pole tests were not considered in the benefit analysis.) The pelvis force measurements are shown below:

Table IV-8
Pelvic Force Measurements
ES-2re, 50^{th} Test Dummy
20 mph Oblique Pole

	Average	Std. Dev.	Max.	Min.
Pelvis Force w/o Th Bag (N)	2,511	896	3,373	1,585
Pelvis Force W/ Th bag (N)	2,314	869	3,815	903
Pelvis Force, if failed (N)	N/A	N/A	N/A	N/A
Pelvis Force, if met (N)	2,353	845	3,815	903

SID-IIs test results: The SID-IIs measurements resulting from the oblique pole test are shown in Table IV-9.

Table IV-9
Oblique Pole Test Results
With SID-IIs, 5^{th} Female Test Dummy (Build D Version)
With 214-Seating Procedure

Test Vehicle	Air bag / Restraint	HIC (req. 1,000)	Thorax Rib Defl.[18] (mm)	Lower Spine Accel. (req. 82 g) [19]	Abdomen Defl. (mm)	Pelvis (req. 5.1 kN)
2005 Toyota Corolla	Curtain + Torso	418	47	70	49	----
2005 VW Jetta	Curtain + Torso	478	33	54	34	**7,876**
2004 Honda Accord	Curtain + Torso	567	31	63	30	**10,848**
2005 Ford Five-Hundred	Curtain (Canopy) + Torso	**1,173**	37	**92**	57	**6,542**
2004/05 Toyota Sienna	Curtain + Torso	**2,019**	46	67	58	**6,956**
2005 Subaru Forester	Combo	160	31	55	45	4,707
2005 Honda CRV	Curtain + Torso	531	26	68	36	4,670
2005 Chevy Colorado	Curtain	896	31	**135**	59	**9,387**
2005 Ford Expedition	Curtain (Canopy) + Torso	**5,661**	35	**96**	53	**8,249**
2005 Saturn Ion	Curtain	**5,203**	32	**110**	52	**5,755**

Note: Failed measurements are shown in bold

[18] The rib deflection was measured at the upper rib of the test dummy.
[19] Resultant acceleration.

Head: A HIC_{36} of 1,000 was used as the injury criterion. This injury criterion is the same as for the 50th percentile test dummies. The results in Table IV-9 show that four out of ten vehicles exceeded the HIC requirement, although all air bags deployed. The average, maximum and minimum HIC scores are shown in Table IV-10.

Table IV-10
Head Injury Measurements
With SID-II D, 5th Female Test Dummy
In Oblique Pole Tests

	Average	Std. Dev.	Max.	min.
HIC (w/ Head Bag)	508	239	896	160

The results in Table IV-10 show an average HIC of 508 when air bags met the proposed HIC requirement. At this HIC level, there are 10.19%, 2.67%, 0.23% and 0.01% of AIS 3, AIS 4, AIS 5 and fatal head injury risks, respectively.

Chest. The rib deflection and lower spine acceleration measurements are shown below:

Table IV-11
Chest Injury Measurements[1]
SID-IIs, 5th Female Test Dummy
In Oblique Pole Tests

Chest Def w/o Th bag (mm)	33	2	35	31
Chest Def w/ Th bag (mm)	36	8	47	26
Chest Def, if failed (mm)	N/A	N/A	N/A	N/A
Chest Def, if met (mm)	N/A	N/A	N/A	N/A
Low Spine Accl w/o Th bag (g)	114	20	135	96
Low Spine Accl w/ Th bag (g)	63	7	70	54
Low Spine Accl, if failed (g)	108	19	135	92
Low Spine Accl. , if met (g)	63	7	70	54

1. For the benefit analysis, thorax bags that failed to meet the lower spine acceleration requirement were excluded from the chest deflection with thorax air bags.

The results in Table IV-11 show that the thorax air bags reduced the lower spine acceleration considerably, from 114g to 63g, although the rib deflection measurements show a slight increase in deflection. The 5^{th} percentile female dummy chest measurements show similar results as the 50^{th} percentile male dummy in the oblique pole tests: a considerable reduction in lower spine acceleration but a slightly higher deflection with thorax bags, for the 5^{th} dummy.

Pelvis. The pelvis measurements show an unusually high failure rate. More than 50% of the vehicles exceeded the require pelvis force of 5,100 N. The pelvis force measurements are shown in Table IV-12.

Table IV-12
Pelvis Injury Measurements
SID –IIs D 5^{th} Female Dummy
In Oblique Pole Test

	Average	**Std. Dev.**	**Max.**	**Min**
Pelvis Force w/o Th bag (N)	7,797	1,858	9,387	5,755
Pelvis Force w/ Th bag (N)	6,933	2,300	10,848	4,670
Pelvis Force, if failed (N)	7,945	1,749	10,848	5,755
Pelvis Force, if met (N)	4,689	26	4,689	4,670

The results in Table IV-12 show average pelvis forces of 7,797 N and 6,933 N with and without thorax air bags, respectively. When all vehicles meet the requirement, the results indicate that an average pelvis force of 4,689 N would be measured, which is about 41% reduction in pelvis force when compared to a force that would be measured if all vehicles failed to meet the requirement.

Discussion

Test to test Variability: In its response to the FMVSS No. 214 PEA, the Alliance said, "the agency did not conduct replicate tests for each proposed test mode or provide an estimation of the error in the data (i.e., mean and variance) in the PEA." (Docket: NHTSA-2004-17694-52.) Since the publication of the PEA, the agency has conducted a series of pole and MDB tests. The additional data enabled us to attain a set of statistical parameters to evaluate and understand the test-to-test variability and effectiveness in circumstances other than the proposed test conditions. One of the most crucial findings is that head air bags are extremely effective in reducing head injuries when the head is restrained by the air bag within its operating range. In the pole test with the ES-2re dummy, the average "deployed" HIC was 504 with a standard deviation of 202, and the HIC ranged from 171 to 806, regardless of vehicle and bag types, as shown below:

Table IV-15
Maximum and Minimum HIC Scores vs. Injury Risk
Deployed Air Bag, All Vehicle Type, All Bag Type
ES-2re 50th Male Test Dummy
Oblique Pole, Prasad/Mertz Distribution

HIC		AIS 3	AIS 4	AIS 5	Fatal
Maximum:	806	25.57%	7.97%	0.95%	0.04%
Minimum:	171	1.52%	0.39%	0.03%	0.00%

Even at the maximum HIC level of 806, the results show there is an extremely small chance of being killed from head injuries when the head of an occupant impacts with an inflated head bag in a head-to-pole impact at a vehicle delta-V of 20 mph in side crashes: four out of 10,000 chances. The statistical analysis of the HIC scores show that, about 99.4% of all head bags that meet the HIC requirement would produce HIC scores within 100 to 908 (i.e., with 2σ) assuming the HIC scores have a normal distribution. The HIC scores measured with a 5th female test dummy exhibited a similar result, as shown below:

Table IV-16
Maximum and Minimum HIC Scores vs. Injury Risk
Deployed Air Bag, All Vehicle Type, All Bag Type
SID-IIs D 5th Female Test Dummy
Oblique Pole, Prasad/Mertz Distribution

HIC		**AIS 3**	**AIS 4**	**AIS 5**	**Fatal**
Maximum:	896	30.89%	10.67%	1.42%	0.06%
Minimum:	160	1.35%	0.35%	0.02%	0.00%

V. BENEFITS

This chapter estimates the potential benefits of the requirements. These benefits would be achieved from the required test and new injury criteria using pre-MY 2006 vehicles as the base. The benefit calculations are based on limited available laboratory crash tests and real-world crash data. The process and theory are presented in the methodology section.

The laboratory test data used in the analysis were generated with two different types of test dummies, the EuroSID-2re (ES-2re) and the SID-IIs[20] in the proposed oblique pole and the MDB tests.

Outline of the benefit chapter & calculation: There were 9,270 fatalities in side impacts in 2004. Of these, we developed several specific target populations for which we believed or could show that the countermeasures would supply benefits. These were further divided into head/face, chest, abdominal, and pelvic injuries for analysis. Benefits from electronic stability control systems (see Appendix D) and FMVSS No. 201 upper interior head protection were subtracted from these target populations to get the final fatal target population, as shown in Table V-A.

The benefit analysis is categorized into two groups: (1) benefits from fatality reduction, and (2) benefits from nonfatal MAIS 3-5 injury mitigation. The general procedure is to first identify the baseline target population and then to estimate the fatal or injury reduction rate/percentage, using the pre-2005 injury probability as the base. Pole and

[20] SID-IIs Build "D" version. See additional discussion in the background chapter.

MDB test results from Chapter IV and other test data are used to calculate fatality and injury probability reductions. The injury reduction rate is applied to the corresponding target population, which results in fatality or injury reduction benefits.

Table V-A
Outline of the benefit chapter & calculation

Crash	Where to Find Calculation (tables)	Fatal Target* Population	Estimated Benefits if No Air Bags in Fleet (lives saved)	Incremental** Benefits Over MY 2011 Fleet
Front, near-side, pole/tree	V-15, V-94, V-102	169	124	32
Front, near-side, vehicle to vehicle	V-15, V-94, V-102	1,382	675	234
Sub Total		1,551	799	266
Rear, near-side, pole/tree	V-105, V-110	2	2	0
Rear, near-side, vehicle to vehicle	V-106, V-110	26	19	5
Sub Total		28	21	5
Far-Side	Page V-82	1,274	209	40
Sub Total		1,274	209	40
Total		2,853	1,029	311

* Adjusted with the ESC and 201-potential benefits, ** Rounded to the nearest integer.

For each target population group, unless otherwise stated, the analysis provides benefit estimates for the oblique pole test with a hypothetical air bag system based on current production head protection system[21] (HPS) performance (referred to “the production HPS” hereafter).

According to weighted 2000-2004 NASS/CDS, 2004 FARS, 2004 GES side impact data, head/face (49%), chest (44%), and abdomen (7%) are the most frequent fatal injuries[22]. We have dummy measurements in these areas and also in the pelvis. Therefore, for the benefit analysis, head, chest, abdomen and also pelvic injuries are considered[23].

[21] Some HPS provide both head/face and thorax protections.
[22] MAIS 1+ occupant injuries in non-rollover near-side impact with damaged lateral zone: P, Y, Z with DOF in 1-5, 7-11, lateral delta-V of 12 – 25 mph.
[23] See additional discussion on the target population in the following section.

The hypothetical HPS used for the analysis are linked together with current and potential technologies. One of these technologies is an "air curtain" type system (referred to as AC hereafter). This system would provide head and neck protection for front and possibly rear occupants[24] in outboard seating positions in side crashes, as the air bags are designed to deploy from a vehicle's roof rail. The air bags can be designed to remain inflated longer than frontal air bags to provide occupant protection during vehicle rollovers[25]. A second type of side air bag is a "torso" (or "thorax") side air bag that can be installed in either the seat or the vehicle door. As the name indicates, the system would provide protection for the torso, but not for the head. A third type is the "Inflatable Tubular Structure" (ITS). The ITS is an inflatable device that is fixed at two points, one at the front end of the vehicle's A-pillar and the other at the back end to the roof rail behind the B-pillar and is installed under the roof rail headliner. When deployed, the ITS inflates to become a self supporting tube that spans the vehicle's side window diagonally and provides head and neck protection. The ITS remains inflated for a few seconds and would provide some additional protection during rollover events and secondary impacts. The last type is a "combined" type (also called "integrated" or "combo") that incorporates both head and thorax bags into one unit. They provide a wide range of protection by combining the technologies used in other head air bag systems. Although different types of head protection systems could be used to comply with the FMVSS No. 214 pole requirements, curtain bags (AC) (as a stand alone system or combined with a

[24] See section V.F for additional discussion.
[25] The head and side air bag systems may need a designated rollover sensor to deploy the bags in rollover crashes. Curtain bags that are designed to meet the proposed 214 requirements may not be large enough to cover front window opening areas in all rollover crashes.

thorax air bag, AC + Th) are becoming the most popular among head air bag systems (or HPS), in particular among sports utility vehicles, as shown in Table V-1.

Table V-1
MY 2004, 2005 and Projected MY 2011
Head/Thorax Air Bag Systems Availability
Estimated, Percent by Total Sales of Passenger Cars, SUV, Vans, and Light Trucks
(Total Numbers in Parentheses)

MY	Thorax only	Curtain (AC) + Thorax (Th)	Combo	AC only	ITS + Thorax
2004	9.48% (1,618,914)	15.19% (2,595,269)	4.74% (810,456)	3.61% (616,204)	2.11% (359,870)
2005	9.72% (1,725,017)	21.18% (3,760,392)	7.31% (1,298,437)	3.67% (651,150)	1.29% (228,650)
2011	0.47% (78,823)	67.38% (11,295,538)	5.28% (884,551)	19.19% (3,217,511)	1.57% (263,770)

The vehicles considered for the target population include old model vehicles. These old model vehicles may not have adequate countermeasures for chest protection, as required by the current FMVSS No. 214 MDB test. Consequently, these old model vehicles would result in relatively higher chest deflection scores when compared to relatively modern vehicles that may or may not be equipped with thorax air bags for side impacts. In the FMVSS No. 214 FRIA, modern vehicles were used as a baseline to derive the effectiveness. These baseline vehicles would result in lower chest deflection scores when compared to old model vehicles in side crashes. (In other words, the baseline used for the real world effectiveness would have a higher chest deflection when compared to the baseline used, for the analysis, in the FRIA.) Ideally, therefore, a derivation based on real world crashes would result in a higher effectiveness rate when compared to the effectiveness derived in the FMVSS No. 214 FRIA. However, for head injuries, head air bags are relatively new and, consequently, a small portion of vehicles considered in the target population would be equipped with head air bags. Therefore, the effectiveness based on the pole test would be very close to the head bag effectiveness based on real world crashes.

The rest of this chapter is organized as follows: the first section (V.A) establishes the baseline target population. The second section (V.B) discusses the methodology for deriving the reduction in fatality and injury rates. The third section (V.C) estimates benefits for improving occupant protection benefits (fatalities and MAIS 3-5 injuries) from the pole tests. Benefits for fatalities and MAIS 3-5 injuries are discussed separately for each relevant test. The benefit summary section (V.D) provides overall benefits in a table format for all the tests. Section V.E discusses any related issues that would affect the benefit estimates. Section V.F shows benefits vs. air bag system. Finally, section V.G discusses head injury risk distribution: Prasad/Mertz and the lognormal (by Hertz).

A. Target Population

A pre-2005 baseline target population is used to estimate benefits since the majority of vehicles were not equipped with head air bags. The NHTSA pole test results show that these vehicles would not meet the head injury criterion without head protection system (HPS) when they are subjected to the oblique pole test. For the analysis, the target population is defined as occupants who sustained fatal[26] and/or AIS 3 or greater injuries

[26] According to 2004 FARS data, a total of 2,311 fatalities occurred for a delta-V range of 12 –25 mph, annually. These fatalities are approximately 24.9% of all fatalities occurred in side crashes, as shown below:

	Fatalities	% of Total
Total Passenger Vehicle Occupant Fatalities in Side Impact Crashes:	9,270	100.0%
Rollover, First Event:	306	3.3%
No Rollover, Kids*:	394	4.3%
No Rollover, Adult, Non-designated Seats**:	102	1.1%

to the head, chest, abdomen and pelvis (i.e., injuries that would be influenced by head or thorax air bags) in side crashes.[27] In addition, it was assumed that all vehicles in the fleet for the target population[28] are not equipped with HPS. (In other words, we didn't adjust the target population for the current effectiveness of HPS or thorax air bags since there are so few of them on the road in our 2000-2004 data collection time frame.)

The agency limited the target population to crashes in which the vehicle delta-V was in the range of 12 to 25 mph. In the April 1997 Preliminary Regulatory Evaluation (PRE) for FMVSS No. 201, the agency determined that the ITS would inflate at a vehicle delta-V of 12 mph. We believe this will be a typical HPS deployment speed for all side crashes. Thus, we chose 12 mph as the lower end of the range.[29] As for the HPS upper impact speed limit, the agency performed a high energy pole impact test to estimate the bottoming out speed for a typical head air bag. In the pole test, a 2004 model year 4-door Honda Accord was tested to a 30 mph oblique pole impact. Based on the estimated

No Rollover, Adult, Far Side Impact, Belted:	1,436	15.5%
No Rollover, Adult, Far Side Impact, Unbelted:	1,441	15.5%
No Rollover, Adult, Rear-Outboard Near Side, Not 12-25 mph***:	316	3.4%
No Rollover, Adult, Rear-Outboard, Near Side 12-25 mph***:	41	0.4%
No Rollover, Adult, Front-Outboard Near Side, Not 12-25 mph***	2,724	29.4%
No Rollover, Adult, Front-Outboard Near Side, Complete Ejection, 12-25 mph	199	2.1%
Target Population, Front-Outboard, Near Side, 12-25 mph***:	2,311	24.9%

* No adjustment made for kids because the change would be 1 (adjustment rate = 1.0019)
** Non-designated seats means seats other than outboard and center, e.g., on someone's lap
*** Delta-V derived from CDS (2001 –2003)

[27] For the benefit estimate, to avoid a "double-counting" of the injuries, MAIS scale was used instead of AIS scale.

[28] Theoretically, we'd like to only include vehicles that met the dynamic side impact tests (Moving Deformable Barrier test specified in FMVSS No. 214) in the target population. These vehicles would be considered as modern vehicles in terms of side protection. However, we don't have enough cases in our sample to do this meaningfully. For the pole/tree impact tests, we don't believe this will make much of a difference. The current vehicles (which pass the 214 dynamic test) have very high HICs in the pole test (without the countermeasures) and we don't believe changes made to the side structure or side doors for the dynamic test will have any benefit for head injuries in pole/tree impacts and very little benefit for vehicle to vehicle tests.

[29] See Chapter XI for additional discussion on the upper end of the range.

energy absorption and the impact speed, we estimate that the head air bag bottomed out at a vehicle delta-V of about 22 mph. In addition to the Honda Accord test, we analyzed high-speed sled data provided by BMW. The high-speed sled data showed that the ITS would bottom out at a vehicle delta-V of about 28 mph. Since different types/configurations of head bags would have different bottoming out speeds, for the analysis, we assumed that the HPS bottoms out at a vehicle delta-V of 25 mph. (Additional discussion on the bottoming out speed is presented in this chapter.)

In essence, 25 mph is assumed to be an average number; in some cases the air bags would be effective above 25 mph and in other cases they would not be effective in the 23-25 mph range, depending upon the crash circumstances and what the occupant's head hit.

Target fatalities and MAIS 3-5 injuries are derived from 2000-2004 CDS. For fatalities, the annualized front-outboard occupant fatalities from CDS are adjusted to the 2004 FARS level to overcome the underreporting problem in CDS for fatalities. (See Discussion section for occupants in rear-outboard seating positions.) As for injuries, the annualized target MAIS 3-5 injury population was adjusted to the 2004 GES CDS-equivalent level to get a better national estimate. For the target population, occupants with heights of at least 65 inches are assumed to be represented by the 50th percentile male dummy (the ES-2re), and the remaining occupants are assumed to be represented by the 5th percentile female dummy (i.e., the SID-IIs). Several additional adjustments are made, as discussed below:

1. <u>Children.</u> Children (0-12 years old) were excluded from the benefit analysis because the majority of the current head air bag systems would not span either forward or low enough, specifically the air chambers (although the webbing may span forward in the window opening), to provide a sufficient contact surface with the head and other body regions. Although the agency believes future head protection system (HPS) may provide children substantial benefits, these potential benefits were not considered for the analysis due to limited data. (In addition, we do not consider a reduction in benefits resulting from children being out-of-position (OOP) from thorax air bags. Side air bag testing of child dummies in OOP situation has shown no problem for HPS systems mounted on the roof rail (window curtain and the ITS). In addition, the automobile manufacturers have voluntary standards for OOP testing and to date the agency is not aware of any serious OOP child injuries due to side air bags.)

2. <u>Out-of-position Occupants</u>. Test results from static testing of side impact air bags using three and six year old Hybrid III dummies and the 12-month CRABI dummy show that several vehicles exceeded injury thresholds with the NHTSA procedures. (See "Side Air Bag Research: Static Testing of Side Impact Air Bags Using Three and Six Year Old Hybrid III Dummies and the 12 Month CRABI Dummy," Aloke K. Prasad, Randa R. Samaha, Allison E. Louden, January 2002.) However, some vehicle manufacturers and researchers suggested that HPS (such as the AC system) would not produce injury measurements higher than the injury criteria. For example, as part of their HPS study, Volvo tested the inflatable air curtain (AC) system with different size test dummies including child dummies in different occupant positions. Based on the test results, Volvo

reports that the AC system would not produce injury values higher than the injury criteria for the dummies in out-of-position (OOP). (For additional discussion, see “The Inflatable Air Curtain – A new head protection system in side impacts.” 16th International Technical Conference on the Enhanced Safety of Vehicles, Paper Number 98-S8-W-29.) Further, in an analytical study, A. Khadilkar and L. Pauls investigated three cases regarding side air bag deployment: inadvertent air bag firing, out-of-position occupant, and unnecessary air bag deployment. In the out-of-position case, a 5th percentile adult female dummy was positioned such that it was leaning to the side against the stowed side air bag. One of the conclusions the study made is that the injury measurements for the 5th percentile female are relatively low across all body segments, including head, chest-g, ribs, abdomen, hip joints and hip restraint with the air bag optimized for the 50th percentile adult male. Although the study has brought up important safety issues regarding out-of-position occupants, as the authors stated in the study, the results are valid within the constraints of the database used in the model. (For additional discussion, see “Assessment of Injury Protection Performance of Side Impact Air bags for Out-of-Position and Other than 50th percentile Adult Male Occupants.” 16th International Technical Conference on the Enhanced Safety of Vehicles, Paper Number 98-S8-W-30.)

Regarding adverse consequences of head and thorax air bags, Ferrari commented that the agency needs a more thorough assessment of adverse consequences of the proposal (in response to the PEA, Docket Number NHTSA-2004-17694-28, page 5). In addition, the Alliance said that when a higher dummy response occurred with the deployed air bag case, the potential dis-benefits were ignored by the agency (Docket NHTSA-2004-17694-

52, page 13). We disagree. A recently performed agency data analysis, dated April 11, 2005, concludes that no fatalities have been attributed to the deployment of a side air bag. In five side air bag cases involving children in which the air bag (side or curtain) deployed, there were no serious injuries attributed to the bag. According to the data, there were only one seriously injured (AIS-3) <u>driver</u> attributed to the deployment of a side air bag (or side air bag cover flap). (The agency data search was performed using the SCI Online Database. Children were considered 12 years of age and under. Vehicle model years ranged from 1995 to 2004. Crash years ranged from 1994 to 2004.)

3. <u>Dummy injury measurements with respect to impact direction (i.e., 75 and 90 degrees from the vehicle vertical longitudinal plane).</u> For the analysis, it was assumed that head injury measurements made with the different test dummies are not "direction sensitive" for the proposed pole test impact directions of 75 and 90 degrees. In other words, the analysis does not distinguish dummy HIC measurements resulting from the 75-degree pole test from measurements resulting from the 90-degree pole test at a given impact speed. The head injury criterion, HIC is calculated based on a scalar sum of the axial accelerations measured with a tri-axial accelerometer instrumented in the head of a test dummy. Thus, although HIC measurements from the 75-degree and 90-degree pole tests would be different due to differences in head configuration, interaction between the head and vehicle components, seating position and other factors, the measurements don't need to be adjusted based on the impact angles.

4. Occupant head, chest, abdomen and pelvic injuries with respect to impact direction. For the benefit analysis, it was assumed that the injury probability curves developed for head, chest, abdomen and pelvis in side impacts (i.e., 90-degree) are applicable to the oblique (75-degree) pole impact. That is, a given injury parameter result will produce the same probability of injury regardless of the angle of impact.

5. Occupants in Rear Outboard Seating Positions. With the test procedure having the pole hit the front door, rear-seating protection is not addressed by our test procedure. Although side-curtain type (AC) HPS would provide protections for head and other body regions for occupants in rear outboard seating positions in some side crashes because of how wide they typically are, most of the other HPS (that would comply with the proposed requirement) would not provide the protection because they would cover only the front seating area and not the rear. (Note that a separate analysis was performed and presented in the Discussion section to estimate benefits for occupants in rear outboard seating positions.)

6. Effectiveness of Safety Belts in Non-rollover Side Crashes. According to a technical report by Dr. Kahane, "Fatality Reduction by Safety Belts for Front-Seat Occupants of Cars and Light Trucks," December 2000, DOT HS 809-199), safety belts reduce fatalities in side impacts by 21% in passenger cars and 48% in light trucks. Fatality reduction due to wearing a safety belt is smallest for nearside impacts, as shown in Table V-2. Kahane reports that nearside impacts to passenger cars often involve compartment intrusion where safety belts are unable to prevent fatalities, while the compartments of light trucks,

often with higher sills and seating heights, are less vulnerable to intrusion and allow safety belts to accomplish their benefits of preventing ejection and mitigation impacts with interior components. Regarding rollover, Kahane said that belts are highly effective in rollovers, where the majority of unbelted fatalities result from ejection. Effectiveness is high in light trucks (80%) and in cars with 3-point belts (74%), and it is slightly lower in cars with 2-point belts (62%). (The full report is seen at http://www.nhtsa.dot.gov/cars/rules/regrev/evaluate/809199.html.) Based on our knowledge of occupant kinematics, for the analysis, it was assumed that safety belts have no impact on the effectiveness of head air bags in non-rollover nearside side crashes; consequently, the target population was not separated by safety belt usage. An analysis was performed and presented in this chapter to estimate the change in benefits that could result from an increase in safety belt use.

Table V-2
Fatality Reduction (%) by Safety Belts

Crash Type		Cars (3-point belt)	Light Trucks (3-point belt)
Frontal Impact		50	53
Side Impact:		21	48
	Near Side	10	41
	Far Side	39	58
Rollover (Primary)		74	80

7. Vehicle Delta-V vs. Occupant Delta-V. Vehicle structure absorbs part of the impact force in side crashes. In order to relate crash speed (i.e., vehicle delta-V) to occupant delta-V, previously developed conversion factors were used. As discussed in the Final Economic Assessment (FEA) for FMVSS No. 201, Upper Interior Head Protection, Monk, Gabler and Sullivan developed an estimate of the relationship between vehicle and

occupant delta-V[30]. In their study, Monk et al. computed velocity and displacement time histories from laboratory collisions for various collision modes. In the FEA, we concluded that the average percent delta-V's experienced by the occupant are very similar for all injury levels, with a maximum variation between any injury level of only one percent, and a maximum variation from the mean percent of only 0.8 percent. Based on the study, an occupant conversion factor of 0.769 was used for the conversion, unless otherwise stated. For example, a vehicle impacts with a pole at a vehicle delta-V of 20 mph, the test dummy would impact with the pole at 15.38 mph (i.e., occupant delta-V of 15.38 mph = 20 x .769).

8. Impact Angle. As discussed briefly in the methodology section, the oblique test would promote the use of wider air bags than the perpendicular pole test. A narrow head air bag may not provide benefits during an oblique crash since the head of an occupant would be moving off at an angle, and may go around the effective part of the air bag, rather than coming directly into the head/chest air bag. In other words, with its narrow width, performance of combo and thorax side air bags would be sensitive to the direction of the impact force in side crashes. For example, one out of four combo air bags that were most likely designed for the FMVSS No. 201 optional pole test (i.e., the perpendicular pole impact test) failed to meet the proposed head injury criterion (i.e., HIC of 1,000) tested with the ES-2re, whereas, all 11 curtain air bags (including canopy curtain bags) met the oblique pole tests with the ES-2re. (Note that combo air bags designed to comply with the proposed pole test(s) would be less effective when compared to curtain air bags in rollover crashes due to its relatively smaller size, assuming that the air bags deploy.)

[30] See Table IV-24 on page IV-44 in the FEA 201.

In response to the PEA, Docket NHTSA-2004-17694-53, page 14, DaimlerChrysler said, "we are aware that the NHTSA has encountered specific cases where a vehicle designed to meet the 90-degree pole impacts failed to detect the 75-degree oblique pole impact. Generally, sensing robustness relative to a range of impact locations and angles has to be one aspect of engineering for side impact protection. While NHTSA has created this situation in its laboratory testing, we are not aware of this as a real world issue."

The agency's test results show that there is a clear indication that head air bags (and probably thorax bags) designed for the 90-degree pole impact are not wide enough to protect occupants because either bags are too small or sensors failed to detect the impact. As the test results indicate, we believe the 75-degree oblique pole impact is needed to protect occupants from a wide range of side crashes. Subsequent to the publication of the PEA, the agency investigated real world side crashes where the side air bag failed to deploy, as shown in Table V-3. Note that the rows highlighted are crashes where we believe the side air bag should have deployed, based on our experiences on investigating crashes. In particular, the Tahoe crash[31] (Case number: 2004-47-156) investigation shows that a narrow impact object came into the front part of the door, near the A-pillar, but the side impact sensor on the B-pillar did not deploy the air bag or detect the crash.

[31] The Tahoe has one side impact sensor at each front door, "The Rescuer's Guide to Vehicle Safety Systems," holmatro, 2nd edition.

The Tahoe crash is similar to the oblique side impact pole testing where the pole (aimed at the head of a 5th female test dummy when it was sitting full forward) came into the front part of the door, near the A-pillar.

Table V-3
Side Impacts Into A Tree or Poll with Side Airbag Non-deployment
2002-2005 Sample Year (*Data Run 5/3/2005)*

Case	Veh. Num.	Vehicle	Delta-V (mph)	Comments
2002-47-081	1	2000 BUICK REGAL	UNK.	Sideswipe
2002-48-073	1	2001 GMC FULLSIZE JIMMY/YUKON	UNK.	Sideswipe Non-Horizontal
2003-02-063	1	2002 CHEVROLET TRAILBLAZER (2002 and later)	UNK.	Minor Damage
2003-09-018	1	2001 MITSUBISHI MONTERO	7.5	
2003-09-232	1	2001 LINCOLN NAVIGATOR	5.6	
2003-41-110	1	2002 HONDA ACCORD	33	80º PDOF
2003-43-155	2	1997 INFINITI Q45	UNK.	Minor Damage
2003-43-201	1	2002 ACURA RSX	9.3	
2003-43-263	1	2002 GMC JIMMY/TYPHOON/ENVOY	6.8	
2003-45-209	1	2004 MERCEDES BENZ 200/220/230/240/250/260/280/300/320 SE,CD,D,SD,ETC	5.6	
2003-49-082	1	2003 NISSAN / DATSUN ALTIMA	MOD.	
2003-49-181	1	2000 CHEVROLET FULLSIZE BLAZER (K, Tahoe)	UNK.	Non-Horizontal
2003-73-176	2	2003 HONDA PILOT	UNK.	Sideswipe
2003-82-079	1	2002 VOLKSWAGEN JETTA	UNK.	Sideswipe
2004-02-084	1	2004 HONDA CR-V	UNK.	Sideswipe
2004-04-024	1	2003 SUBARU IMPREZA	MOD.	80º PDOF
2004-04-101	2	2003 HYUNDAI SANTA FE	13.7	50º PDOF
2004-11-213	1	2003 FORD CROWN VICTORIA	8	
2004-12-191	2	2000 CHEVROLET LUMINA APV/VENTURE	7.5	10º PDOF
2004-13-079	1	2003 FORD THUNDERBIRD (ALL SIZES)	UNK.	Minor Damage
2004-47-156	1	2002 CHEVROLET FULLSIZE BLAZER (K, Tahoe)	13.7	290º PDOF, Behind A-Pillar
2004-49-006	1	2001 HYUNDAI SONATA	UNK.	350º PDOF
2004-49-027	2	2000 CADILLAC DEVILLE/FLEETWOOD	31	50º PDOF
2004-79-001	1	2003 LINCOLN LS	17.4 7.5	320º PDOF
2004-81-091	2	2003 CHEVROLET TRAILBLAZER (2002 and later)	5	
2005-08-040	2	2002 BUICK LESABRE/CENTURION/WILDCAT	1.9	
2005-13-045	1	2000 HYUNDAI SONATA	17.4	280º PDOF
2005-50-006	1	2001 HYUNDAI SONATA	MOD.	100º PDOF
2005-50-036	1	2002 TOYOTA AVALON	18	40º PDOF
2005-74-038	2	2003 HONDA ACCORD	UNK.	Non-Horizontal

Note: MOD: moderate; UNK: unknown

The results of the crash investigation suggest that some manufacturers would need to provide 2 crash sensors on each side of the vehicle, one on the side rail near the center of the front door and one on the side rail near the center of the rear door.

Although it is unlikely that vehicle manufacturers design head/side air bags to just cover the pole impact area to comply with the proposed requirements, for the analysis, it was assumed that air bags are wide enough to just cover the pole impact area (i.e., minimum pole impact area) in its inflated stage and that the sensors are designed exclusively to activate for the impact angle. (In other words, the target population was adjusted by "impact area" and also by "impact angle.") According to a dimensional analysis performed on selected vehicles, the angle between the vertical lateral plane passing through C.G. of the head and the pole vertical planes passing through the boundary of the projected pole coverage areas are found, as shown in Figures V-1 and V-2 and also in Tables V-4 and V-5.

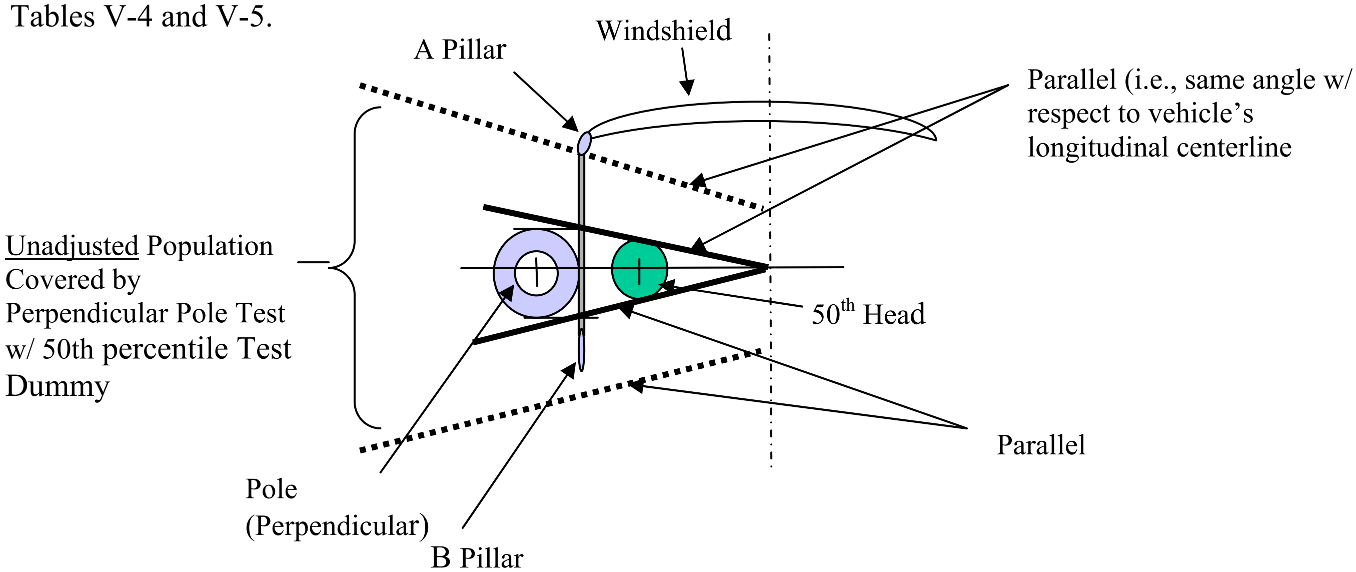


Figure V-1. Overhead View of the Perpendicular Pole and the 50th Percentile Driver Dummy

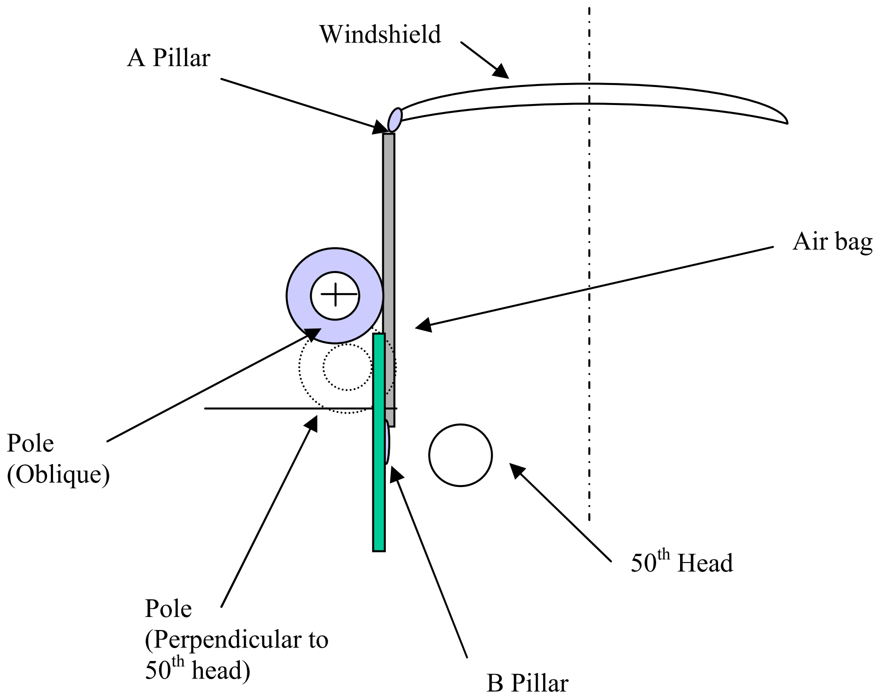


Figure V-2. Illustration of Pole Position: Overhead View of the Perpendicular and Oblique Poles with 50th Dummy

Table V-4
Longitudinal Distance Between 50th and 5th Dummies

Vehicle	Distance Between Head and Windshield (HW) (mm)		Distance Between Dummy's Heads (mm)
	5th Percentile Dummy (SID-IIs)	50th Percentile Dummy (ES-2)[32]	
2002 Chevrolet Impala (NHTSA: R20151, R20127)	576	591	15
2002 Saab 9-5 4 door (NHTSA: RY0519, RY0518)	517	639	122
2001 Ford Focus 4 door (NHTSA: R11317, R11314)	529	584	55
			Avg. 64 mm

[32] The 214 seating procedure was used for the 50th test dummy. R20127 is a side NCAP test, i.e., an MDB test per current 214 but at a higher impact speed, RY0518 is an oblique pole test, R11317 is an MDB test.

Table V-5
Angle between Projected Pole Coverage Area and Vertical Lateral Plane

Average Track Width	**Distance between side window to the vehicle longitudinal centerline**[1]	**Applicable Angle (for the target population)**			
		Perpendicular		**Oblique**	
		50th Percentile Test Dummy[2, 3]	**50th and 5th Percentile Test Dummies**[4]	**50th Percentile Test Dummy**[5]	**50th and 5th Percentile Test Dummies**[6]
2001 vehicles: 61.1”	30.56” (776 mm)	81° -100° 260° - 279°	78° - 102° 258° - 282°	73° - 99° 261° - 287°	67° - 102° 258° - 293°
2002 vehicles: 60.3”	30.26” (766 mm)	81° -100° 260° - 279°	78° - 102° 258° - 282°	73° - 99° 261° - 287°	67° - 102° 258° - 293°
Average Angle (degree)			78° - 102° 258° - 282°		67° - 102° 258° - 293°

1. NCAP, NHTSA, Track width.
2. Pole is 254 mm in diameter. (½(254) = 127 mm)
3. $\tan^{-1}$[(127 mm)/(776 mm)] = 9.29°
4. $\tan^{-1}$[(127 + (½)64)/776] = 12° (90° - 12° = 78°)
5. Forward projected area = 127 + center of pole moved = 127 + (Distance between CG of head and window)(tan 15°). Distance between CG of head and window ≈ ½ of Distance between the centerline and window (assumed). $\tan^{-1}$[(127 + 104)/776] = 16.58° (90° - 16.58° = 73°)
6. $\tan^{-1}$[(127 + 168- (1/2)(64))/776] = 23° (90° - 23° = 67°)

Note that the derived angles are calculated at the horizontal center on the lateral plane that passes through the equidistance point of the head of the 5th and the head of the 50th test dummies. The minimum (average) air bag coverage areas were derived, as shown in Table V-6.

Table V-6
Maximum Impact Angle

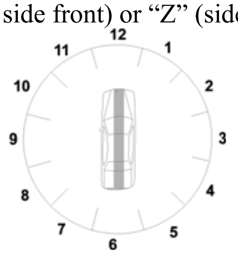
	Perpendicular		Oblique	
	50th Percentile Test Dummy	50th and 5th Percentile Test Dummies	50th Percentile Test Dummy	50th and 5th Percentile Test Dummies
Averaged Maximum Impact Angle (degree)	81° -100° 260° - 279°	78° - 102° 258° - 282°	73° - 99° 261° - 287°	67° - 102° 258° - 293°
Range	19°	24°	26°	35°

Based on our analysis, in a perpendicular pole test using a 50th percentile male dummy, we would cover a range of 19 degrees in impact angles. Using a 5th percentile female dummy increases the range by 5 degrees to 24 degrees. With an oblique pole and a 50th percentile dummy, we would have 26 degrees in impact angle coverage, and adding the 5th dummy to the oblique pole test results in 35 degrees in impact angle coverage.

Note that side crashes are not evenly distributed with respect to impact point in side crashes. According to 2000-2004 NASS CDS, front-outboard, MAIS 1+ occupant injuries, with a lateral delta-V range of 12-25 mph in side crashes, 36% of the injuries are in 3 & 9 o'clock and 92% of the injuries are in 2-3 & 9-10 o'clock directions[33].

9. <u>NASS and FARS Data for Occupant Injuries in Side Crashes.</u> The analysis assumes that HPS benefits only occupants in the front outboard seating positions when the <u>front occupant compartment</u> (including the B-pillar) is struck in vehicle-to-pole and vehicle-to-vehicle side crashes and also complete occupant ejection cases. Accordingly, injuries resulted from these seating positions were used for the analysis, although front compartments impacts are not coded separately in the NASS and FARS data sources. It seems reasonable to assume that all serious front occupant injuries resulted from front occupant compartment crashes, because front occupants are more vulnerable to serious

[33] For the impact point, we used the following parameters: Deformation Location: (GAD1) = "R" or "L" (right or left side); Specific Longitudinal or Lateral Location (SHL1) = "P" (side center), "Y" (side center + side front) or "Z" (side center + side rear); Direction of Force (DOF1) = 1-5, 7-11.



injuries when the front compartment of the vehicle is hit, as opposed to impacts to the rear occupant compartment.

10. <u>Vehicle Impact Speed and Occupant Injuries.</u> The injuries are categorized by lateral vehicle delta-V. The reason for the use of the lateral impact speed[34] rather than the actual impact speed is to include only side impacts that trigger the sensors. For example, if the actual impact speed were used in a 75-degree oblique impact with a vehicle delta-V of 12 mph, instead of the lateral impact speed, the analysis would include the crash since it appears that the crash would activate the sensors (sensors designed to respond to an impact at 12 mph). However, in reality, the crash should not be included since the corresponding lateral impact would be 11.27 mph, which is lower than the assumed activation impact speed of 12 mph. Thus, the impact would not activate the air bag. On the other hand, the use of the lateral impact speed would place injuries at lower delta-V categories. For example, if the head of an occupant experiences an AIS 3 injury in a 75-degree oblique impact with a vehicle delta-V of 20 mph, the injury would be categorized as AIS 3 injury at a vehicle delta-V of 18.8 mph when the lateral impact speed is used. Since the HPS effectiveness is grouped by delta-V, the potential benefit estimate would be affected by applying the effectiveness derived for a vehicle delta-V of 18 mph, rather than for a vehicle delta-V of 20 mph, for the AIS 3 injury. Nevertheless, the use of the lateral impact speed would capture all injuries that would benefit from the required tests and exclude those that would not.

[34] The lateral impact speed is an impact speed that would be measured in parallel with the vehicle's vertical transverse (x) plane. See SAE J1100 APR97 SAE Recommended Practice.

11. Electronic Stability Control (ESC). DaimlerChrysler commented that the PEA has not recognized the benefits of Electronic Stability Control (ESC) in reducing loss of control in side impacts with narrow objects (Docket # NHTSA-2004-17694-53). Although a small fraction of vehicles on the road are equipped with ESC, our preliminary data show that ESC has a relatively high effectiveness rate in preventing crashes (i.e., helping to prevent skids, spinouts and rollovers). For this analysis, we adjusted the target population with the potential ESC benefits. According to the agency data, there were 8,508,891 cars and 9,692,269 trucks in 2003 model year. Among these vehicles, we determined that 11.4% and 8.1% of cars and trucks have ESC in 2003, respectively, as shown in Table V-6. Based on data provided to the agency for its Buying a Safer Car program, and 2004 Ward's data, the agency estimated that 19 percent of the MY 2005 light vehicle fleet will have electronic stability control. This final rule has a relatively long lead time, and we believe that nearly all applicable new vehicles will be equipped with ESC about at the same time as this final rule becomes effective (MY 2011). Accordingly, we assume 100 percent ESC installation as our baseline estimate.

Table V-7
Percent of Vehicles Equipped with ESC, In MY 2003

	Traction Control	Stability Control	ABS	Total # of Vehicle
Cars	30.2%	11.4%	57.7%	8,508,891
Trucks	15.3%	8.1%	91.4%	9,692,269

Table V-8
Percent of Vehicles Equipped with ESC
In MY 2005 (Predicted, with Estimated Number of Vehicles, < 10,000 GVWR)

	Traction Control	Stability Control	ABS	Total # of Vehicle (in millions)	% of total Vehicle	Weighted % ESC
Cars	33.1%	15.1%	56.5%	8 (47%)	47%	
Trucks	30.9%	22.4%	91.1%	9 (53%)	53%	19.0%[35]

[35] 15.1% x 47% + 22.4% x 53% = 19%

According to the agency's data[36], ESC is highly effective in preventing crashes in both single and multiple vehicle crashes (SVC and MVC, respectively). The data show that LTVs have a higher ESC effectiveness rate[37] when compared with passenger cars. According to FARS (2000 – 2004), we determined that ESC has 35% and 67% effectiveness rates in preventing single vehicle side crashes of passenger cars and LTVs.

Table V-9
ESC Effectiveness Rate
(with 100% ESC installation rate)

Crashes	Culpable (ESC impacted portion)	% of Cars in Culpable	% of LTVs in Culpable	Car Eff.	LTV Eff.	Weighted ESC Eff.	ESC Affected Fleet
SVC	0.90	0.66	0.34	0.35	0.67	0.459	41%
MVC	0.52	0.70	0.30	0.00	0.38	0.114	6%

The target population (for occupants in nearside seating positions) was categorized into two groups: vehicle-to-pole/tree and vehicle-to-vehicle/others in side crashes. The target population adjusted with the ESC benefits is shown in Table V-10.

Table V-10
Target Population Adjusted with ESC Benefits
By Crash Mode, Fatality

Crash (fatal)	Reduction in Target Population
Vehicle-to-pole/tree	41%
Vehicle-to-vehicle/others	6%

For non-fatal MAIS 3+ injuries, the following reduction rates were used for the analysis.

[36] See Appendix D for additional discussion.
[37] ESC Effectiveness for both passenger cars and SUVs are based on state crash data (Florida, Maryland, Missouri, and Utah), 1997-2002, and also FARS, 1997-2003 data.

Table V-11
Target Population Adjusted with ESC Benefits
By Crash Mode, Non-Fatality AIS 3+ Injuries

Crash (non-fatal, AIS 3+)	Reduction in Target Population
Vehicle-to-pole/tree	35%
Vehicle-to-vehicle/others	2%

(An additional discussion on the ESC effectiveness is provided in Appendix D in this chapter.)

12. Voluntary Commitment. The Alliance commented the PEA has not recognized the voluntary changes manufacturers will be making. The Alliance said, "The benefit analysis should consider the voluntary changes manufacturers will be making. Baseline should be industry's voluntary commitment and the existing IIHS side impact test procedure, not the characteristics of model year 2003 fleet, . . . The agency did not consider the benefits derived from voluntary industry commitments and design enhancements (Alliance, Docket: NHTSA-2004-17694-52)." The Alliance further said, "The agency's proposal does not adequately recognize the commitments Alliance member, and others, made in December 2003." It said, "Without the proposed regulation, the world continues to be influenced by the voluntary commitment and the other technological advances in safety." For the existing Voluntary Commitment on front-to-side impact protection, the agency does not know whether all vehicle manufacturers would design and produce their vehicles to meet the voluntary commitment. Thus, there is no guarantee that the voluntary commitment would provide consumers a minimum safety protection in side crashes where the head impacts with a tree or pole. In addition, there is no system to monitor whether vehicle manufacturers meet the voluntary commitment or enforce vehicle manufacturers who fail to meet the

voluntary commitment. Furthermore, the IIHS test does not require the air bag to be extended toward the A-pillar the way that our 5th female tests, seating full forward. All light vehicles will be equipped with ESC about at the same time as this final rule becomes effective. As we assume 100 percent ESC installation as our baseline estimate, we will include projected voluntary air bag installation.

Relevant Side Crashes: As discussed in the methodology section, percent reduction rate (and also effectiveness) of HPS depends not only on delta-V but also crash mode/environment. For example, a HIC score resulting from a head impact with a pole would be higher than a HIC resulting from a head impact with the vehicle's padded B-pillar at the same occupant delta-V. Since the percent reduction rate is defined as the percentage reduction in the fatality and injury probabilities, these two cases would produce different percent reduction rates resulting in different benefit estimates. In addition, since the target population is based on the 2000-2004 CDS data, some of these vehicles would be in compliance with FMVSS No. 201, Upper Interior Head Protection. The potential benefits, in terms of lives saved, are adjusted for compliance with FMVSS No. 201 Upper Interior Head Protection requirements[38]. The Alliance (Docket: NHTSA-2004-17694-52) said, "The target population affected by the proposed regulation should include all potentially injured occupants of relatively modern vehicles for whom the countermeasures are designed. By including older model year vehicles in the current analysis, there is a risk that the potential benefits from the proposed regulation will be overestimated. Vehicles built on or after the 1990 model year are a more appropriate basis upon which to build a target population. These vehicles more appropriately

[38] See Appendix B for the derivation.

represent the modern crashworthiness of vehicles with respect to side impact occupant protection countermeasures." Although the commenter states that vehicles built on or after the 1990 model year are a more appropriate basis, the commenter did not provide any supporting data to show how these vehicles are more appropriate. If all non-1990 year or older models were excluded, we believe that the exclusion would present a potential problem for the benefit estimate. The exclusion would reduce the sample size (2000-2004 crash data), substantially. As a result, the smaller sample size, with the agency's limited laboratory test data, would make the benefit estimate more uncertain. Although the target population includes relatively old model year vehicles, we believe we can adjust appropriately, and air bag effectiveness is based on the test results from relatively modern vehicles. To reflect the effect of crash mode/environment, the target population is further divided into three (3) subgroups, as shown below:

Case 1. <u>Side Crashes Involving **Vehicle-to-pole crashes:**</u> Table V-12 shows near side occupant fatalities and injuries in vehicle to narrow (non-deforming) objects (mostly trees and poles) non-rollover non-ejection light vehicle side crashes. The target population is divided into two groups: a group represented by a 50th percentile male dummy and a group represented by a 5th percentile female test dummy. The injuries are categorized by MAIS and body region: head, chest, abdomen (when applicable) and pelvis. Note that we did not include only the NASS or FARS cases where the head of an occupant impacts with a tree or pole. In other words, some of head injuries would result from head-to-pole impacts and others are from impacts with the vehicle interior components, other occupants or external objects.

According to the 2000-2004 NASS CDS data, 75% of the injuries[39] are from occupants represented by the 50th percentile test dummy and the remaining 25% of the injuries are from occupants represented by the 5th percentile female test dummy. These percentages were used to separate the injuries. In their comments, Docket NHTSA-2004-17694-52, the Alliance said, "The agency's assertion that the 5th dummy represents 35% of the target population lacks support in the PEA. No field data, anthropomorphic data, or crash test data is presented to support this assertion." The reasons that we assume, those below 65 inches are represented by the 5th female are: (1) we have two side impact dummies, the 5th female dummy is about 59 inches tall, the 50th male dummy is about 69 inches tall, 64 inches is mid-point, (2) 64 inches is very close to a typical height for a female[40], we felt that this height was better represented by a 5th female than 50th male, (3) this is the same split we used in the advanced air bag final rule issued in May, 2000.

Table V-12a
Target Population for Vehicle-to-Pole Side Crashes (for a delta-V of 12 – 25 mph)
For Occupant Height of at least 65 inches (represented by 50th percentile male dummy)

Body Region	MAIS 3	MAIS 4	MAIS 5	Fatality
Head & Face	27	89	83	224
Thorax	161	153	0	35
Abdomen	0	0	0	0
Pelvis	0	0	0	0
Others	237	0	0	20

Table V-12b
The remaining population represented by a 5th percentile test dummy

Body Region	MAIS 3	MAIS 4	MAIS 5	Fatality
Head & Face	9	30	28	74
Thorax	54	51	0	11
Abdomen	0	0	0	0
Pelvis	0	0	0	0
Others	78	0	0	8

[39] As discussed, AIS 3+ injuries are considered. By using the MAIS scale, rather than the AIS scale, we considered the most serious body injury for occupants with serious injury to more than one body region.
[40] According to SAE J833, the 1998 SAE Handbook, A small human has a standing height of 1,550 mm. The small human represents the 5th percentile female. Only 5% of the female population is smaller than the 1,550 mm.

For the fatalities, 298 resulted from head & face injuries, 46 resulted from chest injuries, and none resulted from abdominal or pelvic injuries. As for the MAIS 3-5 injuries, 266 resulted from head & face injuries, 419 resulted from chest injuries, and none resulted from abdominal or pelvic injuries.

Case 2. Side Crashes Involving **Vehicle-to-Other Vehicles or -Roadside Objects**: Near side occupant fatalities and injuries involving vehicle-to-other vehicles or roadside objects in non-rollover non-ejection light vehicle side crashes are shown in Table V-13. The crashes include occupant partial ejection and also the head impacts with vehicle interior component cases. For the analysis, vehicle interior components include the B-pillar (including seat belt shoulder anchorage), the A-pillar and the roof side rail components[41]. The target population is divided into two groups: represented by a 50th percentile male dummy and by a 5th percentile female test dummy. The injuries are categorized by MAIS and body region: head, chest, abdomen and pelvis, as shown in Table V-13 below.

Table V-13a
Target Population for Vehicle-to-Vehicle & Other Objects in Side Crashes
(for a delta-V of 12 –25 mph)
For Occupant Height of at least 65 inches (represented by 50th percentile male dummy)

Body Region	MAIS 3	MAIS 4	MAIS 5	Fatality
Head & Face	399	187	92	488
Thorax	1,698	400	9	550
Abdomen	11	50	35	110
Pelvis	216	0	0	50
Others	518	54	0	256

[41] Typical curtain air bags cover the B-pillar, and most of combo air bags are installed in the seat back and would prevent the head from impacting the B-pillar. Regarding the roof side rail components, we believe that the deployed air bags restrain the head and/or shoulder from reaching the roof rails in side crashes.

Table V-13b
The remaining population represented by a
5th percentile test dummy

Body Region	MAIS 3	MAIS 4	MAIS 5	Fatality
Head & Face	133	62	30	163
Thorax	566	133	3	183
Abdomen	4	16	12	36
Pelvis	72	0	0	17
Others	172	19	0	86

For these fatalities, 651 resulted from head/facial injuries, 733 resulted from chest injuries, 146 resulted from abdominal injuries and 67 resulted from pelvic injuries. As for the MAIS 3-5 injuries, 903 resulted from head injuries, 2,809 resulted from chest injuries, 128 resulted from abdominal injuries and 288 resulted from pelvic injuries.

Case 3. Side Crashes Involving Occupants in **Far Side Seating Positions**: A recent study done by Kahane shows that the combination of torso and head protection reduces fatality risk in all side impacts, except far side impacts to belted occupants, by 20 percent for drivers and right-front passengers. With torso bags only, the bags reduce fatality risk by 12 percent. According to the agency crash data, 1,441 far side fatalities occur in side crashes, annually.

Summary of Target Population:

In the 2004 Fatality Analysis Reporting System (FARS) there were 9,270 side impact fatalities. For our near-side target population, we excluded from these side impact fatalities those cases which included rollovers as first event (306), no rollover involving children (394), no rollover adults in non-designated seats (102), no rollover adults in far side impact, belted (1,436), no rollover adults in far side impact, unbelted (1,441), no rollover adults in rear-outboard near side, not 12-25 mph (316), no rollover adults rear-out board, near side, 12-25 mph (41), no rollover adults in front-outboard near side, not 12-25 mph (2,724), no rollover adults in front-outboard near side, complete ejection, 12-25 mph (199). This left us with a near-side target population of 2,311 fatalities and 5,891 non-fatal serious to critical MAIS 3-5 injuries. The 2,311 fatalities were divided into two groups for the analysis: (1) vehicle to pole impacts (372) and (2) vehicle to vehicle or other roadside objects impacts, which include partial ejections in these cases (1,939). In this target population, 41 percent of the total fatalities (949) are caused by head/face injuries, 34 percent by chest injuries (779) and 6 percent by abdominal injuries (146). In contrast, for the 5,891 non-fatal MAIS 3-5 target population, chest injuries are the predominate maximum injury source accounting for 48 percent (2,809), head/face injuries account for 20 percent (1,169), and abdominal injuries account for two percent (128). Combining all serious to fatal injuries, chest injuries account for 49 percent (4,007), head/face injuries account for 26 percent (2,118) and abdominal injuries account for three percent (274). For these two groups, we made a percent adjustment based on the estimated benefits that would result from ESC, as shown below:

Table V-14
Target Population Adjusted with ESC
(Fatalities and MAIS 3+ For Near-Side Occupants, Delta-V Range of 12 - 25 mph)

Crash Mode	MAIS 3	MAIS 4	MAIS 5	Fatal
Veh-to-Pole:	368	210	72	219
Veh-to-Veh/others:	3,713	903	177	1,823
Total:	4,081	1,113	249	2,042

Among the 2,042 fatalities, 788 were resulting from head injuries, 716 were from chest injuries, 137 were from abdominal injuries, and 63 were from pelvic injuries. We also made an adjustment based on the estimated benefits that would result from the FMVSS

No. 201 upper interior requirements for the A-pillar, B-pillar, and roof side rail[42]. Detailed description of the benefits computation for FMVSS No. 201 is provided in Tables V-26 through V-28.) For the head, chest, abdomen and pelvis injuries, the fatalities for each crash mode are shown below:

Table V-15
Fatalities Adjusted, Front Occupants
With ESC and FMVSS No. 201
Head, Chest, Abdomen and Pelvis

Crash Mode	Head	Chest	Abdomen	Pelvis	Total
Veh-to-Pole:	142	27	0	0	169
Veh-to-Veh/others:	493	689	137	63	1,382
Total:	635	716	137	65	1,551

Overview of Method

The basic benefit estimation procedure consists of four steps: (1) establish the fatality and AIS 3-5 injury probability (p) for each individual injury criterion (i.e., HIC, rib deflection, abdomen force & deflection, pelvic force); (2) calculate the adjusted and weighted performance of air bags; (3) calculate the reduction rate/percentage (r); and (4) derive benefits. The following is a detailed description of each step.

Step 1. Establish the fatality and AIS 3-5 injury probability (p). This step derived fatal/injury probability (p) for each vehicle test data included in the analysis by injury

[42] For the vehicle-to-pole/tree case, a total of 176 fatal head injuries would occur in vehicle-to-pole/tree side crashes (after adjusted with the ESC benefits, front, near-side occupant). The 2004 fatal injury source data show that 109 of the fatal head injuries would be from head-to-pole/tree impacts and 67 head/face fatal injuries would be from head-impacts-with-vehicle interior components. Among the 67 fatalities, the injury source data show that 45 fatalities would be from head impacts with A or B pillars. The FMVSS No. 201 head form data show that 42 lives from the 45 fatalities could be saved if all vehicles meet the 201-padding requirement. On average, we estimate that 50% of the vehicle in the 2000–2004 period would be 1997 or pre-1997 model year vehicles. In addition, the 202 head form data show that about 42% of these vehicles would be in compliance with the 201 head protection requirement. Fatalities from these vehicles were excluded from the target population. Thus, lives saved by the 201-padding would be 12 [42x0.5x(1-0.42)=12], and the remaining target population would be 33 (45-12 = 33). Additional 201-benefit/adjustment derivations for the vehicle to pole/tree and vehicle to vehicle/other are found in Chapter V and also Appendix C.

criterion. Chapter III provides the algorithms for these curves, based on biomechanical data.

Step 2. Adjust HPS performance for each injury criterion for a particular impact speed. Overall performance of HPS was derived from average injury scores without any adjustment (i.e., simple average). For example, under this approach, HPS would produce an average HIC score of 504 at a vehicle delta-V of 20 mph, when measured with the ES-2re test dummy.

Step 3. Calculate the reduction rate in percentage (r). For each injury criterion, the percentage reduction (r) in the fatality and injury probabilities for each vehicle tested is calculated. For each injury criterion, the reduction percentage (r) is defined as:

$r = 1-(P_a/ P_b)$

P_a : average fatality or injury probability of crash test results with deployed air bags. See following section for further discussion.)

P_b : average fatality or injury probability of crash test results (i.e., baseline, without air bags).

Benefits are realized from the proposed injury criteria. The analysis examines NHTSA pole tests with 50th percentile and 5th percentile test dummies and the test results from vehicle manufacturers and other testing laboratories.

For the benefit estimate analysis, where stated, the fatality and injury reduction rates are estimated based on the actual and estimated production HPS performance based on pole and other relative test results. In other words, the analysis estimates fatality and injury probabilities without setting the injury values to the proposed criteria. The Alliance commented (Docket: NHTSA-2004-17694-52), "Effectiveness calculation should be based on the proposed injury criteria value. However, instead of using the proposed injury criteria, the agency used results from limited testing to estimate effectiveness. If the test result is a value below the proposed injury criteria, the effectiveness will be inflated. For the tests with HPS, the agency calculated average HIC by only using those tests that meet the proposed injury criteria. As a result, the HPS effectiveness rates for mitigating head injury are contrived because all tests with HPS should be considered regardless of the HIC results." We disagree. The agency tries to make its best estimate of what will happen in the future when manufacturers must meet the final rule. In this case, we assume air bag designs like today, and not that they will be <u>redesigned to do poorer</u> and just meet the test requirements.

<u>Step 4</u>. Derive benefits. The last step is to apply the reduction rate to the corresponding target population to estimate benefits:

$B = T_p * r$

Where T_p : target population of the corresponding test.

B: benefits (i.e., lives that would be saved or injuries that would be mitigated) for each injury criterion.

r: reduction rate (i.e., percentage reduction in injury).

Note that the benefits derived from the methodology are for lives saved and injuries prevented for the corresponding injury level. For example, assume that there are 100 fatalities in vehicle-to-pole side crashes at a vehicle lateral delta-V of 20 mph. According to the head injury probability curves, in terms of HIC, there is a 100% probability of death with a HIC score of 14,242 and none with a HIC score of 504. If head air bags reduce the HIC level from 14,242 to 504 at a vehicle lateral delta-V of 20 mph, all the fatalities would be saved and, consequently, the air bag effectiveness at this delta-V would be 100% in the crashes considered. Although the air bag reduced the HIC level by 28 times, some of these occupants would be injured at a vehicle delta-V of 20 mph with the deployed air bag. According to the injury probability curves, there are approximately 10% of AIS 3, 3% of AIS 4 and 0% of AIS 5 & fatal injury probabilities. The lives saved are re-distributed according to the injury probabilities at a HIC score of 504.

Pole Test Results: The agency has conducted a series of pole tests, and the results are summarized in Tables V-16 & -17. As discussed previously, unless otherwise stated, any measured injury scores higher than the injury criteria (for example, HIC of 1,000 for head, etc.) were not considered for the HPS characterization based on an assumption that any vehicle that is not meeting the performance requirements would be in noncompliance. For each test dummy used, minimum, maximum and averages values were calculated (if feasible).

Table V-16
Analysis of HIC Scores w/ the ES-2re (with 201 Seating Procedure)

Speed (mph)	**Impact Angle**	**HPS**	**Head (Min. HIC of 1,000)**		
			Max.	**Min.**	**Avg.**
18	Per.	None	9,004	4,728	6,866
20	Obl.	None	15,591	11,983	14,242
18	Per.	HPS	435	114	230
20	Obl.	HPS	670	243	502

Table V-17
Analysis of the Sled Pole Test Results w/ the ES-2re
(with 214 Seating Procedure, Oblique Impact at 20 mph)

Measurement	Average	Std. Dev.	Max.	min.
HIC (w/ Head Bag)	504	202	806	171
Chest Def w/o Th bag (mm)	41	13	50	26
Chest Def W/ Th bag (mm)	38	5	43	31
Chest Def, if failed (mm)	49	2	50	46
Chest Def, if met Req. (mm)	36	6	43	26
Low Spine Accl w/o Th bag (g)	80	8	90	75
Low Spine Accl w/ Th bag (g)	59	11	75	46
Low Spine Accl, if failed (g)	90	N/A	N/A	N/A
Low Spine Accl. , if met (g)	57	9	75	46
Abd Force W/o Th bag (N)	3,707	2,887	6,973	1,494
Abd Force W/ Th (N)	1,294	296	1,751	841
Abd Force, if failed (N)	4,216	2,395	6,973	2,655
Add Force, if met (N)	1,311	288	1,751	841
Pelvis Force w/o Th Bag (N)	2,511	896	3,373	1,585
Pelvis Force W/ Th bag (N)	2,314	869	3,815	903
Pelvis Force, if failed (N)	N/A	N/A	N/A	N/A
Pelvis Force, if met (N)	2,353	845	3,815	903

The air bags test results show an average HIC score of 230 at a vehicle delta-V of 18 mph, in Table V-16. At a vehicle delta-V of 20 mph, an average HIC score of 502 was measured with the dummy positioned per the FMVSS No. 201 seating procedure and 504 from the FMVSS No. 214 seating procedure. Regarding the chest deflection scores, the ES-2re chest deflection measurements show the tested thorax air bags did not significantly affect the chest deflection <u>in the oblique</u> pole test environment. However, regardless of thorax bags, an average chest deflection of 49 mm was measured with the ES-2re that failed to meet the chest deflection requirement (44 mm). For the test dummy that met the requirement, an average deflection of 36 mm was measured.

Table V-18
Analysis of the Sled Pole Test Results w/ the SID-IIs
(Build "D" version, 214 seating procedure, 20 mph oblique pole)

Measurement	Average	Std. Dev.	Max.	min.
HIC (w/ Head Bag)	508	239	896	160
Chest Def w/o Th bag (mm)	33	2	35	31
Chest Def w/ Th bag* (mm)	36	8	47	26
Low Spine Accl W/o Th bag (g)	114	20	135	96
Low Spine Accl W/ Th Bag (g)	63	7	70	54
Low Spine Accl, if failed (g)	108	19	135	92
Low Spine Accl. , if met (g)	63	7	70	54
Pelvis Force W/o Th Bag (N)	7,797	1,858	9,387	5,755
Pelvis Force W/ Th Bag (N)	6,933	2,300	10,848	4,670
Pelvis Force, if failed (N)	7,945	1,749	10,848	5,755
Pelvis Force, if met (N)	4,689	26	4,689	4,670

* For the benefit analysis, we only considered chest deflections that met the lower spine acceleration requirement.

MDB Test: The test results from the MDB tests are discussed separately in Chapter VIII.

<u>Air bag deployment speed</u>: In the April 1997 Preliminary Regulatory Evaluation (PRE) for FMVSS No. 201, the agency determined that the ITS would inflate at a vehicle delta-V of 12 mph (9.2 mph occupant delta-V). Due to limited test data, this air bag deployment speed is adopted for the analysis for all side crash cases. Thus, unless otherwise stated, the minimum air bag deployment speed of 12 mph was used for the analysis. For the upper operating range, we analyzed test data from a 30 mph oblique pole tests and also the ITS sled tests. In the 30 mph pole test, a 2004 Honda Accord equipped with a curtain air bag was tested according to the oblique pole test procedure. A HIC of 2,520 was measured in the pole test. The dummy acceleration data show that

the head impacted with the deployed air bag at 28 ms; the impact speed was 0.2 mph <u>with respect to the vehicle</u>. After the bag bottomed out, the data show that the head impacted with the pole with an impact speed of approximately 7 mph, as shown below:

Table V-19
Y-component Head Acceleration
30 mph Oblique Pole Impact, ES-2re

Head Impact	Time (ms)	Change in Velocity (Km/hr)	(m/s)	(mph)
With Deployed Air Bag	28.0	0.3	0.1	0.2
With Pole	40.0	11.5	3.2	7.2

Table V-20
Head Impact Speed at Pole and Deployed Air Bag
30 mph Oblique Pole, (With respect to the ground)

	(Km/hr)	(m/s)	(mph)
Vehicle delta-V	48	13	30
Occupant delta-V	37	10	23
Head at Air Bag	36.6	10.17	22.7
Head at Pole	25.4	7.05	15.8

If the kinetic energy associated with the head is dissipated by the air bag, the following energy equation is applicable:

$$\Delta K = \frac{1}{2} m V_i^2 - \frac{1}{2} m V_f^2 \quad Where\ V_i\ and\ V_f\ are\ based\ on\ head\ velocity$$

According to the energy dissipated, we calculated that a head impact speed of 16.4 mph when the head stops at the pole (i.e., bottoming out speed). The corresponding occupant delta-V would be 16.6 mph and the vehicle delta-V would be 21.6 mph. The 30 mph oblique pole test results shows that a typical curtain air bag would bottom out at a vehicle delta-V of about 22 mph when the head of an occupant impacts with a rigid pole in side crashes, as shown below:

Table V-21
If Air Bag Bottoms Out, At Pole

	Impact Speed	
	m/s	mph
Head Impact speed at Air Bag	7.3	16.4
Head Impact speed at Pole[1]	0.0	0.0
Occupant delta-V	7.4	16.6
Vehicle delta-V	9.6	21.6

1. Under the condition, the bag just bottoms out when the head reaches the pole.

In addition to the 30 mph pole test, we analyzed the ITS sled test results previously submitted to the agency (see the Preliminary Regulatory Evaluation of FMVSS No. 201, April 1997, for additional discussion). During the ITS test, a HIC score of 560 was measured with deployed ITS at a vehicle delta-V of 31.69 mph (occupant delta-V of 24.24 mph) when the head impacts with the B pillar. Based on the 30 mph oblique pole test data, we believe that the ITS bag bottomed out during the impact. Unlike a rigid pole, the B pillar would provide head protection even after the air bag bottoms out. Based on the derived ITS HIC profile, as shown in Appendix B, the 560 HIC would correspond an impact speed of 10.3 mph at the B pillar. Similar to the methodology used for the 30 mph pole test, the energy equation yields that the ITS would bottom out at a vehicle delta-V of 28.7 mph (occupant delta-V of 21.9 mph). In summary, based on the 30 mph pole and the ITS sled tests, we estimated that on average the 214-head air bags would bottom out at a vehicle delta-V of 25 mph.

All estimates were based on the assumption that there are no changes in occupant demographics, driver/passenger behavior, or the percent of small stature occupants sitting in the front seat. In addition, the analysis uses data (2000-2004 NASS CDS, annual, adjusted Front Outboard Occupant Injuries in Non-rollover Side Impacts) to derive the target populations that would be impacted by a HPS. The analysis also assumes that the sensors and other mechanical and electronic devices are 100 percent accurate and reliable in performing their designed functions over the vehicle's operational lifetime.

Benefit Estimates

1. Summary

(a) Fatalities

As described in the method section, the reduction percentage is calculated for each test that failed the injury values.[43] Reduction percentages (of injury probability) for impact speeds other than the test speeds are estimated for each target population, as described in the benefit derivation section. Benefits are derived by applying the reduction percentages to the appropriate target population. The analysis gave precedence to head injuries over the other injuries at the same AIS level, if an occupant has a maximum head injury. The oblique pole test would save as much as 788 additional lives[44] if vehicles were equipped with curtain and thorax air bags with 4 side impact sensors, annually, when all vehicles in the fleet meet the standard.

(b) Injuries

Similar to the methodology described in the fatality analysis, injury benefits are derived by applying the reduction percentages to the appropriate injury target population. Head, chest, abdomen, and pelvic injuries were examined separately. The oblique pole test

[43] In some cases, we used the percent reduction in injury risk, rather than the "pass" & "fail" scores.
[44] Among 788 lives saved, 579 are resulting from occupants in front nearside seating positions, 21 are from occupants in rear nearside seating positions and 189 are resulting from occupants in far side outboard and center seating positions.

requirements would prevent 69 AIS 5, 197 AIS 4 and 386 AIS 3 injuries-in vehicle-to-pole and vehicle-to-vehicle/others side crashes if vehicles were equipped with curtain and thorax air bags with 4 side impact sensors.

As discussed in the methodology section, the effectiveness derived for the various hypothetical impact cases were used to derive the benefits. Since the target population was not categorized with a delta-V interval,[45] the benefits were derived based on the effectiveness of HPS at a vehicle delta-V of 20 mph.[46] The target population categories that were considered for the derivation are discussed in the following section.

2. Necessary foundation analysis and evaluation:

In response to the PEA, the Alliance said that the agency had not carried out necessary foundation analysis and evaluation to support the NPRM (Docket: NHTSA-2004-17694-32). We disagree. We believe that the analysis in the PEA is rigorous enough to show potential benefits of the FMVSS No. 214-bags in side crashes. To help the reader to conduct an independent reanalysis, we have incorporated the majority of the data and the derivations used in the analysis in the FRIA. These data and derivations are shown in either in appendices or footnotes, as indicated.

[45] A vehicle delta-V range of 12 –25 mph was used for the target population, rather than each delta-V.
[46] For occupants in far side seating positions, we used the real world head/side air bag effectiveness, without any adjustment made on the bag performance. Since the current bags would be smaller and narrower, in general, the far side occupant estimate would result in an underestimate, when compared to an estimate made with the 214-bag. In addition, we only considered fatalities for the far side occupants. Since the crash test results show that head and thorax bags are effective in reducing not only fatal injuries but also serious AIS 3+ non-fatal injuries, consequently, the exclusion would underestimate the benefits.

<u>Benefit Derivation for the Vehicle-to-pole Side Crashes</u>:

In the impact angle discussion, we estimate that the FMVSS No. 214-bag is wide enough to protect the head in 2 & 3 o'clock and 9 & 10 o'clock PDOF impacts. According to the 2000-2004 CDS data, more than 90% of impacts occurred in these impact directions.[47] Therefore, approximately 90% of the target population (within a lateral vehicle delta-V range of 12-25 mph) would be potentially affected by the proposed oblique pole tests for the 50th and 5th percentile test dummies.[48] For the occupants represented by the ES-2re, 50th percentile test dummy, occupants who are potentially affected by the bags are shown in Table V-22.

Table V-22
Vehicle-to-Pole Target Population, Front, Near Side
Adjusted with ESC, 201-Potential Benefits,
Minimum Bag Size and 50th Occupant Size

Body Region	Injury Level			
	MAIS 3	MAIS 4	MAIS 5	Fatality
Head and Face	16	45	41	92
Thorax	91	86	0	18
Abdomen	0	0	0	0
Pelvis	0	0	0	0

<u>Head</u>: The pole test results, in the case examined, indicate that when the head of a test dummy impacts with a pole, the resulting HIC score is very high. The Alliance said, in

[47] Adult <u>front</u> outboard occupants, MAIS 1+, lateral 12 –25 mph, P, Y, Z w/ DOF in 1-5, 7-11, in non-rollover, near side impact. The bag would be wide enough to protect the head in 2 & 3 o'clock and 9 & 10 o'clock PDOF impacts, as shown below:

Crash	2 O'clock	3 O'clock	9 O'clock	10 O'clock	Total
Veh-to-pole:	9.96%	4.99%	56.56%	15.32%	87%
Veh-to-veh/others:	11.35%	5.02%	28.76%	47.67%	93%

Adult <u>rear</u> outboard occupants, MAIS 1+, lateral 12 –25 mph, P, Y, Z w/ DOF in 1-5, 7-11, in non-rollover, near side impact:

Crash	2 O'clock	3 O'clock	9 O'clock	10 O'clock	Total
Veh-to-pole:	10.71%	76.42%	0.00%	6.37%	94%
Veh-to-veh/others:	29.15%	9.18%	4.64%	49.96%	93%

[48] The ranges in angle, determined in the impact angle discussion, were converted to o'clock position for the target population.

its response to the PEA, Docket: NHTSA-2004-17694-52, "On PEA page V-28, the HIC Values from the crash tests indicates that head impact to a pole will 'result in 100% probability of death', which the agency recognized contradicts the presence of non-fatal head injury in the field (PEA page V-17, Tables V-6 and V-7)." The Alliance further stated, "The likely cause of this contradiction is the use of a very limited number of tests with a specific test configuration." We disagree with the commenter. It appears that the commenter erroneously believes that all vehicle-to-pole crashes would result in the head of an occupant impacting with a pole/tree. As shown in Tables V-6 and V-7 in the PEA, not all vehicle-to-pole/tree crashes result in the head of an occupant impacts with a pole. Some would hit a pole/tree and others would impact vehicle interior components such as B-pillar or roof rail. Even at a low delta-V, there is a high risk of serious injury when the head of an occupant impacts with a pole/tree. For example, even a relatively low impact speed of 15.7 mph (7 m/s), the Volvo pendulum test results[49] show that a direct head impact to a rigid object would result in a HIC score of 3,500. According to the head injury probability curves, the HIC score would result in almost 100% probability of death. On the other hand, the results in Table V-22 show that there is a low risk of severe injuries in vehicle-to-pole side crashes within the 12 –25 mph delta-V range considered. Consequently, the real world crash data show that not all vehicle-to-pole crashes result in head-to-pole impacts; the head may impact with a pole/tree (external objects), vehicle interior components (such as A, B pillars and roof rail), or window opening areas (whether window is in "open" or "closed" position).

[49] "The Inflatable Curtain (IC) – A New Head Protection System in Side Impacts," ESV Paper 98 S8 W 29, Figure 17.

The Alliance, in their comments on the PEA, Docket # NHTSA-2004-17694-52, claimed the methodology ignores that risk of particular types of crashes in the real world and the resultant injury sources in those variable crashes. As the commenter brought up, when a certain crash occurs, such as a vehicle-to-pole impact, the likelihood of the head impacts with interior components, exterior objects or open/closed window would be affected by many factors, such as relative position of the head, impact angle and speed. Since the publication of the PEA, the agency investigated injury sources in real world side crashes. The investigation revealed that, for example, for fatalities that occurred inside vehicles in vehicle-to-vehicle/others crashes, 13.1% of the fatalities occurred when occupants impacted with the A or B pillars and 17.5% of the fatalities occurred when occupants impacted with exterior objects or the striking vehicle, as shown below:

Table V-23
Front Occupant Injury Sources[50] Fatalities Occurred Inside Vehicle
For 12 –25 mph Non-rollover Side Crashes By Crash Type

Vehicle-to-Pole/Tree:	% of total
Windshield	2.6%
Left Side Interior Surface (no hardware)	19.7%
Left A/B Pillars (Majority B Pillar)	20.7%
Other Vehicle or Object in the Environment	49.5%
Non-Contact	7.4%
Total	100.0%

Vehicle-to-Vehicle/Others:	% of total
Steering Wheel Rim and Hub/Spoke	4.0%
Left Side Interior Surface (no hardware)	15.9%
Left Side Interior Hardware/Armrest	14.9%
Left A/B Pillar (Majority B Pillar)	5.3%
Right Side Interior Surface	20.2%
Right A/B Pillar	7.8%
Other Interior (e.g., Roof, Floor)	4.3%
Exterior of other vehicle	17.5%
Non-Contact	3.7%
Unknown Sources	6.4%
Total	100.0%

[50] The injury sources include all body regions.

For the fatal head injuries in vehicle-to-pole/tree side crashes, the injury source data show that 20.7% of all fatalities were resulting from impacts with A or B-pillars. The 2000 – 2004 crash data show that a total of 219 fatalities[51] would occur in vehicle-to-pole/tree side crashes in a delta-V range of 12 –25 mph, annually. Among these fatalities, 176 would be resulting from head/face injuries, as shown in Table V-24

Table V-24
Vehicle-to-Pole/Tree Side Crashes[52]
Lateral Vehicle Delta-V of 12 -25 mph, 2000-2004 CDS, 2004 FARS, 2004 GES
(After adjusted with the ESC potential benefits with 100% ESC installation rate)

Body Region	MAIS 3	MAIS 4	MAIS 5	Fatal
Head & Face	23	77	72	176
Neck	0	0	0	0
Thorax	140	133	0	27
Abdomen	0	0	0	0
Spine	9	0	0	0
Upper Extremity	10	0	0	17
Pelvis	0	0	0	0
Lower Extremity	186	0	0	0
Unknown	0	0	0	0
Total	368	210	72	219

Among the 176 head/face fatalities, some of the fatalities would occur inside vehicles when the head impacts with vehicle interior components, such as A or B pillars. The real world injury sources data show that 20.7% of all fatal impacts occurred at A or B pillars in the side crashes. When fatalities occur outside of vehicles, the ITS sled tests performed by BMW show that fatal head/face injuries would be resulting from the head impacts with a pole or tree in the vehicle-to-pole/tree crashes[53].

[51] After adjusted with potential benefits of the ESC with a 100% ESC installation rate. See Appendix D for additional information on ESC
[52] All injuries have been rounded to the nearest integer.
[53] The data show that there is an extremely low risk of fatality when the head does not impact any exterior object in vehicle-to-pole type crashes, based on the HIC scores.

According to the above injury sources, 109[54] of the fatal head/face injuries are from head-to-pole/tree and 67 head/face fatalities are from head-to-interior component impacts (among the 67 fatal head injuries, 45 would be from impacts with A or B pillars) in vehicle-to-pole/tree side crashes.

For the fatal head injuries resulting from impacts to vehicle's interior components, some could be saved by the FMVSS No. 201 padding. To determine risk of particular types of crashes in the real world and the resultant injury sources in those variable crashes, we examined the real world crash data, as shown below:

Table V-25
Fatal Injury Distribution vs. Speed
1982-1986, in FEA, FMVSS No. 201, page IV-38, Weighted, 12 to 25 mph range

Vehicle Delta-V (mph)	Weighted Frequency
12	7.99%
13	4.07%
14	23.57%
15	1.38%
16	3.72%
17	6.41%
18	3.85%
19	4.71%
20	2.29%
21	8.08%
22	13.87%
23	1.62%
24	13.88%
25	4.57%
Total	100.0%

As discussed previously, some vehicles considered in the target population are relatively old vehicles and would not represent modern vehicles in terms of occupant protection in interior impact (as specified in FMVSS No. 201). Therefore, the FMVSS No. 201

[54] For the non-ejection vehicle to pole/tree crashes, the injury data show that 49.5% of the 219 fatalities were resulting from head impacts with other vehicles. Thus, 219 x 49.5% = 109.

potential benefits were excluded from the benefit analysis, based on real world crash exposure and the risk of injuries. The following table shows the fatal head/face injuries distribution with respect to vehicle delta-V, adjusted with crash frequency and injury risk probability.

Table V-26
Fatal head/face Injuries Distribution with respect to Vehicle Delta-V, Adjusted with Crash Frequency and Injury Risk Probability

Vehicle Delta-V (mph)	Baseline HIC	Risk of Fatality	Weighed Frequency	Fatal Probability	Weighed Fatal Probability	Fatality
12	254	0.00%	7.99%	0.00%	0.00%	0
13	366	0.00%	4.07%	0.00%	0.00%	0
14	479	0.00%	23.57%	0.00%	0.00%	0
15	591	0.01%	1.38%	0.00%	0.01%	0
16	703	0.02%	3.72%	0.00%	0.07%	0
17	816	0.04%	6.41%	0.00%	0.25%	0
18	928	0.07%	3.85%	0.00%	0.26%	0
19	1041	0.14%	4.71%	0.01%	0.65%	0
20	1153	0.27%	2.29%	0.01%	0.61%	0
21	1266	0.52%	8.08%	0.04%	4.12%	2
22	1378	1.00%	13.87%	0.14%	13.62%	6
23	1491	1.89%	1.62%	0.03%	3.01%	1
24	1603	3.53%	13.88%	0.49%	48.10%	22
25	1716	6.53%	4.57%	0.30%	29.30%	13
Total				1.02%	100.00%	45

To estimate the FMVSS No. 201 potential padding benefits, the fatalities (resulting from interior impacts) were further adjusted with the FMVSS No. 201-effectiveness rate, the FMVSS No. 201-compliance rate and the average percent of these vehicles in the 2000–2004 crash period.

Table V-27
FMVSS No. 201-Potential Benefits

Speed (mph)	Effectiveness	Fatalities	Lives Saved
12	0%	0	0
13	0%	0	0
14	0%	0	0
15	100.00%	0	0
16	50.00%	0	0
17	75.00%	0	0
18	71.43%	0	0
19	78.57%	0	0
20	85.19%	0	0
21	88.46%	2	2
22	90.00%	6	6
23	92.06%	1	1
24	93.48%	22	20
25	94.64%	13	13
	Total	45	42

Table V-28
Percent of 1997 and Pre-1997 Vehicles in A Given Year

	2000	2001	2002	2003	2004	Average
% of 1997 & pre-1997 vehicles	63%	56%	52%	43%	38%	50%

Regarding 201 compliance rate, the FMVSS No. 201-head form data show that 42% of the pre-201 vehicles would be in compliance with the FMVSS No. 201 head protection requirements. For example, on average, 50% of the vehicles would be either 1997 or pre-1997 model vehicles. Among these vehicles, 42% would be in compliance with the 201-requirement. Thus, the lives saved by the FMVSS No. 201 padding would be 12 (42 lives x 50% x (100%-42%) = 12). The adjusted fatal head injuries would be 33 (45-12 = 33).

In summary, when adjusted with the ESC and the 201 potential benefits, 142[55] fatal head injuries would occur in vehicle-to-pole side crashes in a delta-V range of 12 – 25 mph, annually. Among the 142 fatalities, 109 would be from head-to-pole/tree impacts and the remaining 33 fatalities would be from head-to-interior components impacts in the delta-V range considered, as shown in Table V-29

Table V-29
Head Injuries in Vehicle-to-Pole/Tree Side Crashes*
Adjusted with ESC and FMVSS No. 201 Potential Benefits
(12-25 mph Vehicle Delta-V, Non-Rollover, Front Occupants, Near-side)

Head Impact Object	MAIS 3	MAIS 4	MAIS 5	FATAL
Head impacts-to-Pole/Tree:	14	48	45	109
Head impacts -to-Vehicle Interior Components:	9	21	19	33
Total	24	69	63	142

* The numbers were rounded to the nearest integer.

For the head impacts with a pole/tree case in vehicle-to-pole side crashes, based on the baseline and deployed head injury probabilities, effectiveness and corresponding benefit for each injury level were derived[56], as shown below:

Table V-30
Bag Effectiveness[57] for Each Injury Level
In Vehicle-to-Pole/Tree Side Crashes

	MAIS 3	**MAIS 4**	**MAIS 5**	**Fatal**
Head-to-pole/tree	---	---	---	99.99%
Head-to-interior components	85.36%	88.76%	93.55%	97.06%

[55] Rounded numbers.
[56] The derivations leading to the effectiveness and additional detailed information on the benefit estimation procedure are shown in Appendix C.
[57] The bag effectiveness is based on HIC scores measured with a test dummy at a vehicle delta-V of 20 mph.

Table V-31
Fatal and Serious Injuries Prevented[58] by Head Air Bag
Head Impacts with Pole/Tree in Vehicle-to-Pole Side Crashes, 12-25 mph
Occupants Represented by 50th Test Dummy
(Injuries: adjusted with ESC potential benefits, 201-benefits and impact coverage area)

	MAIS 3	MAIS 4	MAIS 5	Fatality
Head impacts with pole/tree:	9	31	29	71
Effectiveness:	--	--	--	99.99%
Benefits:	0	0	0	71

The results in Table V-31 show that 71 lives would be saved with deployed air bags when head impacts with a pole or tree in vehicle-to-pole side crashes (12-25 mph vehicle delta-V range). Although the deployed air bag greatly reduces the HIC level, it does not eliminate forces acting on the head. Thus, some of the occupants saved by the air bag would experience less serious injuries. According to the vehicle-to-pole test results, a HIC score of 504 would be measured[59] with a deployed head air bag at the same vehicle delta-V (i.e., a vehicle delta-V of 20 mph). This HIC level would produce injuries (at a HIC of 504) according to the injury probability curves, as shown in Table V-32.

[58] The benefit is derived based on an assumption that all impacts occur at a vehicle delta-V of 20 mph (i.e., a point estimate). Under this assumption, all impacts would result in fatalities at this impact speed. However, the real world crash data show that serious non-fatal injuries in head-to-pole/tree crashes would occur at lower impact speeds or indirect head-to-pole/tree impacts. With the point estimate methodology, these serious head injuries were not considered. (i.e., the denominator of the equation would be "zero.") Consequently, the point estimate would result in an underestimate (by not considering potential benefits from these serious but non-fatal injuries).

[59] The deployed HIC scores are measured with the test dummy in the 214 seating position. Since the HIC baseline for the 214 seating procedure was not available, for the HIC profile, the baseline air bag scores measured with the 201 seating procedure were used. As discussed in this chapter, HIC measurement would be omni directional. Regardless of seating procedure used, the head was positioned such that the pole directly impacts the CG of the head in pole tests.

Table V-32
Redistribution of Fatality Benefits Head Impacts with Pole/Tree
Vehicle-to-Pole Crashes
50th Head Injuries

Injury	AIS 3	AIS 4	AIS 5
Redistribution	7	2	0

The results in Tables V-31 and -32 show that head air bags would save 71 lives but induce 2 AIS 4 and 7 AIS 3 head injuries, annually, as shown below:

Table V-33
Summary of Head Benefits
Head Impacts with Pole/Tree in Vehicle-to-Pole/Tree Side Crashes
50th Occupants, Front, Near-side, Outboard Seating Positions

	AIS 3	AIS 4	AIS 5	Fatality
Benefits	-7	-2	0	71

With respect to the head-to-interior components case (in vehicle-to-pole/tree crashes), when the head of a 50th percentile male dummy impacts with the vehicle interior components, according to the case study, a HIC score of 869 would be measured at a vehicle delta-V of 20 mph. Whereas, with deployed air bags, a HIC score of 316 would be measured[60]. According to the injury risk probability and the number of injuries, benefits were derived for each injury level, as shown below:

Table V-34
Head Benefits for Head Impacts with Vehicle Interior Components
Vehicle-to-Pole Side Crashes
50th Occupants, Front Near-side, Outboard Seating Positions

	AIS 3	AIS 4	AIS 5	Fatality
Injuries:	6	14	12	22
Effectiveness:	85.36%	88.76%	93.55%	97.06%
Benefits:	5	12	11	21

[60] See Appendix B for additional information.

The lives saved and injuries prevented were redistributed with the weighted risk probability at a HIC score of 316, which would be measured with deployed air bags at a vehicle delta-V of 20 mph, as shown below:

Table V-35
Redistribution of Head Injury Benefits
Head Impacts with Vehicle Components Case in Vehicle-to-Pole Crashes
50th Occupants, Front Near-side Outboard Seating Positions

Injury	AIS 3	AIS 4	AIS 5
Retribution	2	0	0

The overall benefits for head-to-vehicle interior components in vehicle-to-pole side crashes are shown in Table V-36.

Table V-36
Summary of Head Benefits
Head Impacts with Vehicle Interior Components
Vehicle-to-Pole/Tree Side Crashes
50th Occupants

	AIS 3	AIS 4	AIS 5	Fatality
Benefits:	3	12	11	21

When there is no head contact or contacts with a side widow/glazing, the BMW ITS sled test results show that a HIC of 190 would be measured with open window at a vehicle delta-V of 27 km/hr (17 mph)[61, 62]. The data show that the ITS produced a HIC of 230 with the deployed bag with open window at the same impact speed. Since deployed air bags would produce slightly higher HIC scores at this vehicle delta-V, head air bags would be ineffective[63]. Consequently, the potential benefits were not derived.

[61] See "BMW AG, Petition For Reconsideration, FMVSS No. 201, Occupant Protection In Interior Impact, Head Impact Protection," September 15, 1995, Docket No. 92-28-04-013.
[62] See "Ejection Mitigation Using Advanced Glazing, Final Report." The documentation is at http://www-nrd.nhtsa.dot.gov/PDF/nrd-11/glazingreport.pdf It reports that maximum (or near maximum) HIC is achieved at the speed just below that which produces glazing fracture, and increasing the impact speed in subsequent test may not result in substantially higher HIC scores.
[63] See Appendix B, the head impacts with open and closed window.

Table V-37
Overall Head Benefits for Occupants Represented by a 50th Dummy in Vehicle-to-Pole/Tree Side Crashes
Front Near-side Outboard Seating Positions

	AIS 3	AIS 4	AIS 5	Fatality
Benefits	-4	10	11	92

The results in Table V-37 show that head air bag would save 92 lives, and prevent 11 AIS 5 and 10 AIS 4 head injuries, but the redistribution of these injuries would result in an increase of 4 AIS 3 head injuries.

For the occupants represented by the **SID-IIs 5th** percentile test dummy in vehicle-to-pole/tree side crashes, the population was adjusted with the minimum air bag coverage, as shown below:

Table V-38
Vehicle-to-Pole Target Population
Occupants Represented by 5th Female Test Dummy
(Adjusted with ESC, 201-benefits and bag coverage)

Body Region:	Injury Level			
	MAIS 3	MAIS 4	MAIS 5	Fatality
Head & Face:	5	15	14	31
Thorax:	30	29	0	6
Abdomen:	0	0	0	0
Pelvis:	0	0	0	0

Similar to the methodology used for the benefits derivation for occupants represented by a 50th percentile test dummy, the 5th head/face benefits were derived based on the target population and the effectiveness derived for the three scenarios in vehicle-to-pole/tree side crashes: head impacts with pole/tree, vehicle interior components and window, as shown below:

Table V-39
Occupants Represented by 5^{th} Female Test Dummy
Distributed by Injury Source and Injury Level
Vehicle-to-Pole/Tree Side Crashes
(Adjusted with ESC and 201 potential benefits and bag coverage)

	MAIS 3	MAIS 4	MAIS 5	Fatality
Head impacts with pole/tree:	3	10	10	24
Head impacts with interior components:	2	5	4	7

Table V-40
Occupants Represented by 5^{th} Female Head/face Benefits
Head-to-pole/tree Impacts
Vehicle-to-pole/tree Side Crashes

	MAIS 3	MAIS 4	MAIS 5	Fatality
Head impacts with pole/tree:	3	10	10	24
Effectiveness:	---	---	---	99.99%
Head/face Benefits:	0	0	0	24

The results in Table V-40 show that 24 lives (occupants represented by a 5^{th} percentile female test dummy) would be saved with deployed air bags when head impacts with a pole or tree in vehicle-to-pole/tree side crashes. Although the deployed air bag greatly reduces the HIC level, it does not eliminate forces acting on the head. Thus, some of the occupants saved by the air bag would experience nonfatal injuries, as shown in Table V-41.

Table V-41
Redistribution of 5^{th} Fatal Head/Face Benefits
Head-to-Pole/Tree
Vehicle-to-Pole/Tree Side Crashes

Injury	AIS 3	AIS 4	AIS 5
Redistribution:	2	1	0

The overall benefits for the head impacts with pole/tree, 5^{th} occupants, in vehicle-to-pole side crashes are shown in Table V-42.

Table V-42
Summary of Head Benefits
Head-to-Pole/Tree Impacts in
Vehicle-to-Pole/Tree Side Crashes, 5th Occupants

	AIS 3	AIS 4	AIS 5	Fatality
Benefits:	-2	-1	0	24

As for the head impacts with the vehicle interior components case, the benefits were derived according to the effectiveness and target population for each injury level, as shown below:

Table V-43
Head Benefits
Occupant Represented by 5th Female Test Dummy
Head-to-Vehicle Interior Components
Vehicle-to-Pole/Tree Side Crashes

	AIS 3	AIS 4	AIS 5	Fatal
Head impacts with vehicle interior components	2	5	4	7
Effectiveness	85.36%	88.76%	93.55%	97.06%
Head Benefits*[64]	2	4	4	7

* Rounded to the nearest integer.

Table V-44
Redistribution of Head Benefits
5th Occupants, Head-Impacts-with-Interior Components
Vehicle-to-Pole/Tree Side Crashes

Injury	AIS 3	AIS 4	AIS 5
Redistribution:	1	0	0

The results in Tables V-43 and -44 were combined to derive the overall benefits for the head impacts with the vehicle interior components, as shown below:

Table V-45
Overall Head Benefits for Head-Impacts-with-Vehicle Interior
Components in Vehicle-to-Pole Side Crashes
Occupants Represented by 5th Female Test Dummy
Vehicle-to-Pole/Tree Side Crashes

	AIS 3	AIS 4	AIS 5	Fatal
Head Benefits:	1	4	4	7

[64] The estimates have been rounded to the nearest integer, although the derivation can estimate in fractional amounts. Subtotals may not add up exactly in the tables because of rounding.

From the results in Tables V-42 and -45, the overall benefits for occupants represented by a 5th female test dummy were derived in vehicle-to-pole/tree side crashes, as shown below:

Table V-46
Head Benefits for Occupants Represented by a 5th
Percentile Female Test Dummy in Vehicle-to-Pole/Tree Sides Crashes

	AIS 3	AIS 4	AIS 5	Fatality
Head Benefits, 5th	-1	3	4	31

The results in Table V-46 show that head air bags would save 31 lives, 4 AIS 5 and 3 AIS 4 injuries, annually. However, head bags would induce 1 AIS 3 additional injury for occupants represented by a 5th female test dummy, annually.

For all occupants in vehicle-to-pole/tree side crashes, 12-25 mph, the results in Tables V-37 and -46 were combined, as shown below:

Table V-47
Head Benefits* in Vehicle-to-Pole/tree Side Crashes
Front, Near-Side Seating Positions, All Occupant Sizes

Occupant	AIS 3	AIS 4	AIS 5	Fatal
50th	-4	10	11	92
5th	-1	3	4	31
Total	-5	13	15	122

* The numbers were rounded to the nearest integer.

The results in Table V-46 show that head air bags would save 122 lives, 15 AIS 5 and 13 AIS 4 head injuries, annually, when all occupants in front, near-side seating positions are considered. However, the bags would increase 5 AIS 3 head injuries.

Chest (Vehicle-to-Pole/Tree): There are two major concerns for the chest benefit derivation[65]: First, we only have the AIS 3+ and AIS 4+ injury risk curves for chest deflection (for the SID-IIs 5th female dummy, addition to the deflection, we have AIS 3+ and AIS 4+ risk curves for lower spine acceleration). Consequently, we do not know AIS 5 or fatality risk resulting from chest injuries in vehicle-to-pole side crashes. Second, the pole test is mainly designed to evaluate head protection in a pole crash by aligning the pole with the C.G. of the head, not the C.G. of the chest. Therefore, the oblique pole test may not represent the worst crash condition in real world crashes that result in serious chest injuries or fatalities. Since current thorax bags are designed to protect occupants from lateral impacts, the bags are likely positioned to provide a maximum protection in these impacts. To achieve this goal, vehicle manufacturers would position the bags such that the center of a deployed bag aligns with the C.G. of the chest. When an impact point moves further from the center of the bag, as seen in the oblique pole, the effectiveness would decrease.[66] Therefore, we speculate that thorax bags would provide a higher overall effectiveness rate in real world narrow object crashes, when compared to the effectiveness derived from the oblique pole test. In other words, the chest benefit estimate made with the oblique pole test results would result in an underestimate when compared to thorax bag benefits in real world crashes. Regarding the first concern, the pole test results indicate that the chest defection measurement was approximately 41 mm without thorax bags at a lateral vehicle delta-V of 19.3 mph (oblique delta-V of 20

[65] For the 50th, the benefit derivation is based on chest deflection.
[66] The Alliance commented that the maximum effectiveness of front air bags is for 12 o'clock and decreases dramatically for 11, 10, 1 and 2 o'clock positions. (Docket: NHTSA-2004-17694-52, Comments on the Preliminary Economic Assessment (PEA)). As stated by the Alliance, the effectiveness would decrease as impact points move further from the intended primary impact point.

mph)[67]. According to the chest injury risk curves, there are 46% probability of AIS 3+ and 19% of AIS 4+ injury probabilities at a chest deflection of 41 mm, as shown in Figure V-3.

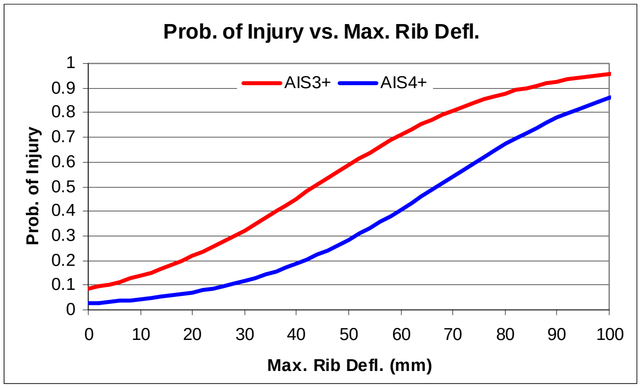


Figure V-3. Probability of AIS 3+ and AIS 4+ Injury
As a Function of Maximum ES-2re Rib Deflection

Although the AIS 5+ injury risk would be lower than the AIS 4+ risk and the fatality risk would be lower than the AIS 5+ injury risk at a chest deflection of 41 mm, we do not have information on AIS 4, 5 and fatal risk at a chest deflection of 41 mm.

According to the 2000-2004 crash data, there were 18 fatalities and 177 serious non-fatal chest injuries for occupants represented by a 50th male test dummy in vehicle-to-pole/tree side crashes, as shown below:

Table V-48
Chest Injury, Occupants Represented by 50th Male Test Dummy
Vehicle-to-Pole/Tree Side Crashes
(12 - 25 mph vehicle delta-V, adjusted with ESC)

	MAIS 3	MAIS 4	MAIS 5	Fatalities
Chest Injuries:	91	86	0	18

[67] Cosine 15° x 20 mph = 19.3 mph.

For the benefit derivation, the effectiveness derived from the vehicle-to-pole test results was used[68]. The chest deflection and lower spine acceleration measurements are shown in Table V-49.

Table V-49
ES-2re 50th Dummy Chest Deflection Results
20 mph Oblique Pole

	Avg. Chest Deflection	Injury Risk		
		AIS 3+	AIS 4+	AIS 3
Without Thorax Bag:	40.7 mm	47%	19%	28%
With Thorax Bag:	37.9 mm	43%	17%	27%
Effectiveness:		7.12%	10.45%	4.89%

The chest deflection effectiveness rates show that 4 AIS 3 injuries would be prevented and 11 AIS 4+ (including fatalities) would be prevented, as discussed in the following section.

For occupants represented by a 50th test dummy, we used the chest deflection measurements for the benefit estimate. In addition, we assume the AIS 4+ effectiveness applies to AIS 4, AIS 5 and fatal injuries. The chest benefit estimates are shown in Table V-50.

Table V-50
Chest Benefits[69], Occupants Represented by 50th Male Test Dummy
Vehicle-to-Pole/Tree Side Crashes

	MAIS 3	MAIS 4	MAIS 5	Fatal	Total
Chest Injuries:	91	86	0	18	
Effectiveness:	4.89%	10.45%	10.45%	10.45%	
Benefits:	4	9	0	2	15

[68] For thorax bags with the ES-2re in the pole test, vehicle manufacturers would install thorax bags to meet the chest deflection requirement In this case, the bag effectiveness would be derived from vehicles "with" and "without" thorax bags. For the vehicle "with" thorax bags, only bags that met the deflection requirement should be considered, since these bags would be in compliance with the requirements.

[69] The estimates have been rounded to the nearest integer, although the derivation can estimate in fractional amounts. Subtotals may not add up exactly in the tables because of rounding.

The results in Table V-50 show that 2 lives, 9 AIS 4 and 4 AIS 3 chest injuries would be saved and prevented for occupants represented by a 50th test dummy. The injuries prevented and lives saved were redistributed at the chest deflection level predicted by the deployed air bag according to the injury probability.

The oblique pole test results show that if all vehicles were equipped with thorax bags, on average, a chest deflection of 38 mm (37.9 mm) would be measured. At a chest deflection of 38 mm, there is a 43% AIS 3+ injury probability. In other words, 57% of the chest injuries prevented by the air bag would results in AIS 1, AIS 2 injuries, or no injury. For the analysis, we assumed the prevented injuries result in AIS 1 or 2. According to these injury probabilities, the lives saved and injuries prevented were redistributed, as shown in Table V-51.

Table V-51
Redistribution of AIS 3+ and Fatal Chest Injuries Prevented[70]
By Deployed Air Bag in Vehicle-to-Pole Crashes

Chest Injury	AIS 1	AIS 2	AIS 3
Redistributed	4	4	7

The overall chest benefits for occupants represented by a 50th percentile male test dummy are shown in Table V-52.

Table V-52
Overall Chest Injury Benefits for Vehicle-to-Pole Side
Crashes for Occupants Represented by 50th Test Dummy

	AIS 3	AIS 4	AIS 5	Fatal
Chest Benefits:	-2	9	0	2

[70] The estimates have been rounded to the nearest integer.

The results in Table V-52 show that if all vehicles were equipped with chest bags, 2 lives and 9 AIS 4 chest injuries would be prevented, annually, for occupants represented by a 50th percentile male test dummy in vehicle-to-pole/tree side crashes. However, the redistribution of the benefits would result in 2 AIS 3 chest injuries[71].

For occupants represented by the SID-IIs 5th percentile female test dummy, the 2000-2004 target populations show that 12 fatalities and 105 serious injuries occur in vehicle-to-pole/tree side crashes, annually. When adjusted with the ESC potential benefits, there were 6 fatalities and 59 serious chest injuries. The chest deflection and lower spine acceleration measurements are shown in Tables V-53a and -53b.

Table V-53a
SID-IIs 5th Chest Deflection Results
20 mph Oblique Pole

	Avg. Chest Deflection	Injury Risk		
		AIS 3+	AIS 4+	AIS 3
Without Thorax Bag	33 mm	31%	6%	25%
With Thorax Bag	36 mm	41%	9%	32%
Effectiveness		---	---	---

Table V-53b
SID-IIs 5th Lower Spine Acceleration Results
20 mph Oblique Pole

	Lower Spine Acceleration	Injury Risk		
		AIS 3+	AIS 4+	AIS 3
Without Thorax Bag	114 g	74%	48%	26%
With Thorax Bag	63 g	49%	24%	25%
Effectiveness		33.5%	49.8%	3.3%

The lower spine acceleration measurements show that thorax bags are about 33.5% and 49.8% effective in reducing serious AIS 3 and AIS 4+ chest injuries, respectively. With the effectiveness rates, 1 AIS 3 and 17 AIS 4+ chest injuries would be prevented by thorax air bags for occupants represented by a 5th female test dummy in vehicle-to-

[71] Based on the assumption that the injuries prevented and lives saved result in AIS 1, 2 & 3 chest injuries.

pole/tree side crashes. However, the assessment made with the chest deflection measurements does not show a clear indication that these benefits would indeed occur with thorax bags for the population. Since we believe the chest deflection is a better prediction of injury than lower spine acceleration, with the limited data, therefore, we assumed that thorax air bags are not effective in preventing chest injuries for occupants represented by a 5th female test dummy in vehicle-to-pole/tree side crashes (in 12-25 mph, in front near-side seating positions), although the assumption would result in an underestimation of the benefits.

The overall injury distributions were combined to derive the net benefit for chest injuries in vehicle-to-pole crashes for all occupants when the 50th (ES-2re) and 5th (SID-IIs) dummies are used in the oblique pole test, as shown in Table V-54.

Table V-54
Lives Saved and Injuries Prevented for All Chest Injuries
Vehicle-to-Pole Side Crashes, Front Near-side

Occupants	AIS 3	AIS 4	AIS 5	Fatal
50th Occupants:	-2	9	0	2
5th Occupants:	0	0	0	0
Total:	-2	9	0	2

The results in Table V-54 show that 2 lives and 9 AIS 4 chest injuries would be prevented when all vehicles are equipped with thorax bags. However, bags would increase 2 AIS 3 chest injuries in vehicle-to-pole side crashes.

Abdomen: The pole test results indicate that when vehicles failed to meet the requirement, the abdomen of a 50th test dummy would experience a force of 4,216 N, on average, at a vehicle delta-V of 20 mph. According to the abdomen injury risk curves, there is a 42.8% chance of AIS 4+ injuries at this force level. If all vehicles met the requirement, an average abdominal force of 1,311 N would be measured. In addition, the results show that an average abdominal force of 3,707 N was measured without thorax bags and 1,294 N with thorax bags. At these force levels, there are 86.6% and 3.6% of AIS 3+ abdominal injury risk, respectively, as shown below:

Table V-55
Abdominal Force Measurements
Occupants Represented by 50th Male Test Dummy
Vehicle-to-Pole/Tree Side Crashes
With and Without Bag

	Avg. Abdominal Force	Injury Risk		
		AIS 3+	AIS 4+	AIS 3
Without Th bag:	3,707	86.6%	20.2%	66.4%
With Th bag:	1,294	3.6%	0.1%	3.5%
Effectiveness:	---	95.8%	99.3%	94.8%

According to the probability of AIS 3+ and AIS 4+ abdominal injury based on Walfisch and Viano, the reduction in abdomen force would not be insignificant in reducing AIS 4+ injuries and fatalities, as shown in Figure V-4.

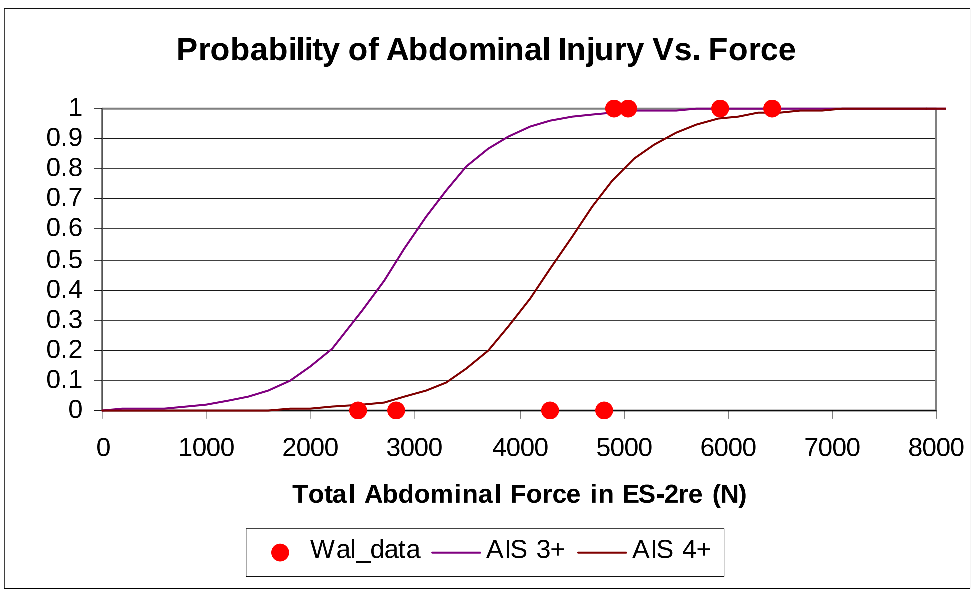


Figure V-4. Risk of abdominal injury as a function of total abdominal force measured in the ES-2re dummy

For the estimate, we used the results from the “with” and “without” thorax bags[72] and assumed that AIS 4, 5 and fatal effectiveness rates are same as the AIS 4+ effectiveness rate, as shown below:

Table V-56
Abdominal Benefits
Occupants Represented by 50th Male Test Dummy
Vehicle-to-Pole/Tree Side Crashes

	MAIS 3	MAIS 4	MAIS 5	Fatal
Abdominal Injuries	0	0	0	0
Effectiveness	94.8%	99.3%	99.3%	99.3%
Benefits	0	0	0	0

For the occupant represented by the SID-IIs 5th percentile test dummy, since the injury criterion is not required in the final rule, benefits were not estimated[73].

Table V-57
Summary of Abdominal Benefits
Vehicle-to-Pole/Tree Side Crashes

Occupant Size	MAIS 3	MAIS 4	MAIS 5	Fatal
50th:	0	0	0	0
5th:	0	0	0	0
Total:	0	0	0	0

<u>Pelvis</u>: For occupants represented by the ES-2re, 50th percentile test dummy, the pole test results show that none of the vehicles failed the requirement. An average pelvic force of 2,511 N was measured without thorax bags at a delta-V of 20 mph. According to the pelvic injury risk curves, there is a 0.79% risk of AIS 3+ injuries at a pelvic force of 2,511 N, as shown in Figure V-5. With thorax bags, an average force of 2,314 N was measured with deployed thorax bags.

[72] In other words, we used the thorax bag effectiveness with respect to abdominal injury.
[73] The 2000-2004 target population for the vehicle-to-pole/tree shows no MAIS 3+ abdominal injuries.

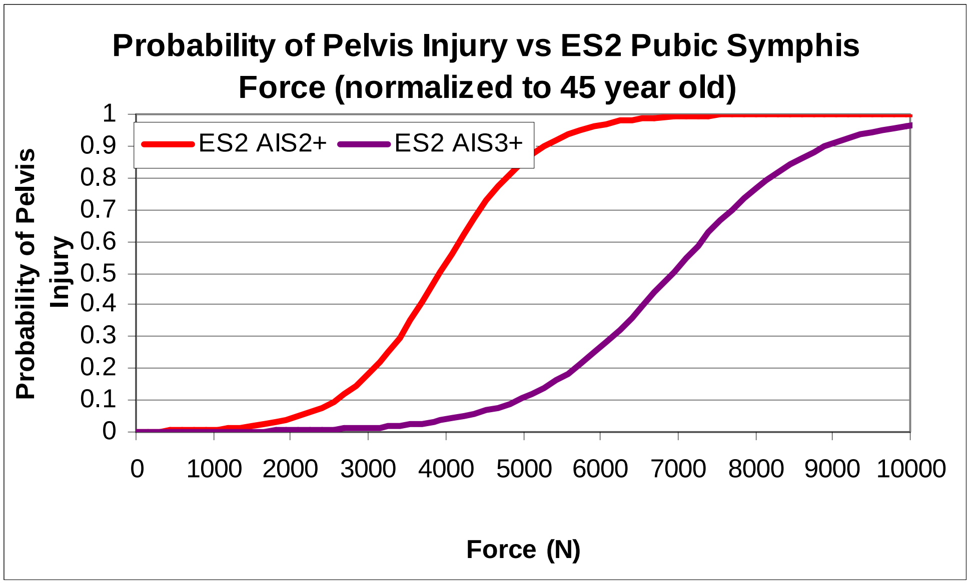


Figure V-5. Probability of AIS 2+ and AIS 3+ pelvic injury as
A function of ES-2 public symphysis force

The target population and the estimated benefits are shown below:

Table V-58a
Bag Effectiveness (Pelvis)
Occupants Represented by 50th Male Test Dummy
Vehicle-to-Pole/Tree Side Crashes

	Pelvis Force (N)	AIS 3+
Without Th Bags	2,511	0.79%
With Th Bags	2,314	0.64%
Effectiveness		19.36%

Table V-58b
Pelvis Benefits

	MAIS 3	MAIS 4	MAIS 5	Fatal
Target Population	0	0	0	0
Effectiveness	19.36%	19.36%	19.36%	19.36%
Benefits	0	0	0	0

The results in Table V-58b show that thorax air bags would not result in any pelvis benefits in Vehicle-to-Pole/Tree side crashes, for occupants represented by a 50th male test dummy.

For occupants represented by the SID-IIs, 5th percentile female test dummy, the following measurements were made:

Table V-59
Pelvis Force Measurement
Occupants Represented by 5th Female Test Dummy
Vehicle-to-Pole/Tree With and Without Thorax Bags

	Pelvis Force	AIS 2+ Risk
Without Thorax Bag:	7,797 N	81.6%
With Thorax Bag:	6,933 N	65.2%
Effectiveness:		20.13%

For the benefit analysis, we used the "with" and "without" thorax bags measurements and assumed the effectiveness rates for AIS 3, 4, AIS 5 and fatal are same as the AIS 2+ injuries. The pelvis benefits in vehicle-to-pole/tree side crashes are shown below:

Table V-60
Pelvis Benefits
5th Occupants, Front Near-side Outboard Seating Positions
Vehicle-to-Pole

	MAIS 3	MAIS 4	MAIS 5	Fatal
Injuries	0	0	0	0
Effectiveness	20.1%	20.1%	20.1%	20.1%
Benefits	0	0	0	0

Table V-61
Overall Pelvis Benefits
Vehicle-to-Pole Side Crashes, Front, Near-side

Occupant	MAIS 3	MAIS 4	MAIS 5	Fatal
50th:	0	0	0	0
5th:	0	0	0	0
Total:	0	0	0	0

The results in Table V-61 show that thorax air bags would produce any pelvis benefits for occupants in the front near side seating positions in vehicle-to-pole/tree side crashes (We note that the assessment is based on the MAIS scale).

For vehicle-to-pole side crashes, the analysis shows that 124 lives, 15 AIS 5, 22 AIS 4 injuries would be saved/prevented annually when the proposed oblique pole test with the ES-2re and SID-IIs is adopted. However, the redistribution of the lives saved and injuries prevented would cause a gain of 7 AIS 3 injuries, as shown below:

Table V-62
Overall Benefits for All Occupants in Vehicle-to-Pole Side Crashes
Near-side Outboard Seating Positions, 12 –25 mph

Body Region	AIS 3	AIS 4	AIS 5	Fatality
Head	-5	13	15	122
Chest	-2	9	0	2
Abdomen	0	0	0	0
Pelvis	0	0	0	0
Total	-7	22	15	124

<u>Benefit Derivation for Vehicle-to-Vehicle and Vehicle-to-Roadside Objects</u>:

In the target population section, we determined that approximately 90% of the target population would be potentially affected by the oblique pole test for the 50th and 5th percentile test dummies. The population was adjusted with the air bag coverage area, as shown in Table V-63.

Table V-63
Vehicle-to-Vehicle/Other Side Crash Target Population
Lateral Vehicle Delta-V of 12 -25 mph, 2000-2004 CDS, 2004 FARS, 2004 GES
Adjusted with ESC Potential Benefits, with 100% ESC Installation Rate
Adjusted with FMVSS No. 201 Potential Benefits and Bag Coverage

Body Region	MAIS 3	MAIS 4	MAIS 5	Fatality
Head and Face	464	216	103	457
Thorax	2,059	485	11	639
Abdomen	14	60	43	127
Pelvis	262	0	0	58

<u>Head</u>: The target head/face injuries were divided into two groups: head impacts with the striking vehicle and head impacts with the vehicle interior components. The fatal injury

sources for vehicle-to-vehicle/others show that approximately 13% of all fatalities that occurred inside vehicles were from impacts with A or B pillars in the delta-V range, as shown below:

Table V-64
Front Occupants, Fatal Injury Sources
Vehicle-to-Vehicle Side Impact

Vehicle-to-Vehicle/Others:	
Steering Wheel Rim and Hub/Spoke	4.0%
Left Side Interior Surface (no hardware)	15.9%
Left Side Interior Hardware/Armrest	14.9%
Left A/B Pillar (Majority B Pillar)	5.3%
Right Side Interior Surface	20.2%
Right A/B Pillar	7.8%
Other Interior (e.g., Roof, Floor)	4.3%
Exterior of other vehicle	17.5%
Non-Contact	3.7%
Unknown Sources	6.4%
Total	100.0%

Similar to the methodology used for the vehicle-to-pole/tree case, the head fatal injuries were separated into two groups[74]: head-to-front of striking vehicle and head-to-interior components, as shown below:

Table V-65
Vehicle-to-Vehicle/Other Side Crash Target Population, 50th Occupants
Lateral Vehicle Delta-V of 12 -25 mph, 2000-2004 CDS, 2004 FARS, 2004 GES
Adjusted with ESC Potential Benefits, with 100% ESC Installation Rate
Adjusted with FMVSS No. 201 Potential Benefits and Bag Coverage

	MAIS 3	MAIS 4	MAIS 5	Fatal
Head & Face:	348	162	77	343
Thorax:	1,544	364	8	480
Abdomen:	10	45	32	96
Pelvis:	196	0	0	44

[74] See Appendix B for detailed derivation.

Table V-66
Head Injury Source
Vehicle-to-Vehicle/Others Side Crashes
Adjusted with ESC, 201-Benefits, Coverage and 50th Occupants[75]

	MAIS 3	MAIS 4	MAIS 5	Fatal
Head-impacts-with-striking vehicle	189	89	43	222
Head-impacts-with-veh. Inter. components	159	74	34	121
Total	348	162	77	343

The results in Table V-66 show that for occupants represented by a 50th percentile male test dummy 222 fatalities were from head-to-front of a striking vehicle and 121 fatalities were head-to-vehicle interior components in vehicle-to-vehicle side crashes in a vehicle delta-V range of 12 –25 mph.

Regarding head injuries resulting from head impacts with the striking vehicles, the current NHTSA moving deformable barrier (MDB) would not be tall enough to simulate such impacts. Based on our experience, even occupants in low profile vehicles would not experience such impacts in the agency's MDB test. For example, in our recent FMVSS No. 214 compliance tests, a 2005 Subaru Legacy weighting 3,715 lbs. and a 2005 Buick Lacrosse weighting a little over 4,000 lbs. were tested at the FMVSS No. 214-compliance speed of 33.5 mph. The Subaru had a lateral delta-V of approximately 14.5 mph and the Buick had a lateral delta-V of approximately 12 mph. (These approximations are taken from acceleration data collected by the y-component of a tri-axial accelerometer placed at the c.g. of the struck vehicle.) During the tests, no head contact was observed. Although head impacts to the striking vehicle/barrier are rarely seen in the FMVSS No. 214-MDB

[75] For the analysis, we assumed that the injury sources are applicable to all occupants involved in the side crashes, although we suspect that 5th females would have a higher frequency of hitting the striking vehicles and interior objects because of their heights when compared to 50th occupants. See Appendix E for detailed derivation.

test, such impacts could occur in real world crashes. For example, a 2003 Mitsubishi Outlander LS weighting 3,444 lbs. was tested with the IIHS MDB at an impact speed of 31 mph (50 km/h) at the institute. (Although the lateral delta-V of the struck vehicle is not available, based on our experience, we estimate a lateral delta-V of approximately 15 mph.) The vehicle was not equipped with side air bags. The results show that the head of the driver dummy was hit by the intruding barrier resulting in high head injury measures. According to the institute, the HIC_{15} measured was 972[76]. At this HIC level, serious skull fracture and brain injuries could occur. We note that these lateral delta-V speeds are much lower than the impact speeds observed in the 20 mph oblique pole impact. If the vehicle were impacted by the barrier at a higher delta-V (such as 20 mph), the HIC level would be much higher than 972. Even with a simple linear approximation[77] (i.e., draw a straight line), the resulting HIC would be about 2,000 at a lateral delta-V of 20 mph. At this HIC level, there is a 26% chance of fatality and 72% chance of AIS 3+ non-fatal injuries. As shown in the Volvo's pendulum test[78], HIC would increase drastically as impact speed increases. Although we believe that the HIC score would be much higher than 2,000 at a lateral delta-V of 20 mph, we do not have test data to show HIC levels when the head impacts with the striking vehicle at a delta-V range of 12 – 25 mph (other than the data from the IIHS tests). The Volvo's pendulum

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[76] In addition to the Mitsubishi, a 2003 Suzuki Grand Vitara without side air bags was tested at the institute. The intruding barrier hit the dummy's head. A HIC of 958 was measured.
[77] Since the HIC varies with the 2.5 power of the head acceleration and the impact speed energy to be dissipated varies with the square power of the impact speed, the liner approximation would result in a underestimation of the HIC.
[78] See Appendix B for additional discussion.

test results[79] show that HIC scores of approximately 700, 2,000 and 3,500 at impact speeds of 4 m/s, 6 m/s (13.4 mph) and 7 m/s (15.7 mph), respectively.

Table V-67
Impact Speed vs. HIC
Pendulum Test and IIHS MDB

Vehicle Delta-V (mph)	HIC, Baseline
11.63	700
15.36	965
17.45	1,900
20.36	3,400

For the analysis, based on the IIHS crash data and the Volvo pendulum data, we estimated a HIC of 2,939 at 20 mph for the head impacts with the striking vehicle in vehicle-to-vehicle crashes[80]. For the head bag effectiveness, we examined reduction in HIC with and without head air bags, as shown below:

Table V-68
Injury Probability without Head Bags

Head Impact		Injury Risk			
	HIC	AIS 3	AIS 4	AIS 5	Fatality
Head-to-Striking Vehicle	2,939	0.42%	0.41%	0.46%	98.66%
Head-to-Veh. Interior Components	869	29.33%	9.80%	1.26%	0.05%

Table V-69
Injury Probability with Head Bags

Head Impact		Injury Risk			
	HIC	AIS 3	AIS 4	AIS 5	Fatality
Head-to-Striking Vehicle	458	8.34%	2.16%	0.18%	0.00%
Head-to-Veh. Interior Components	316	4.29%	1.10%	0.08%	0.00%

Based on the results in Tables V-68 and -69, the bag effectiveness rate was derived, as shown below:

[79] Paper Number: 98 S8 W 29, "The Inflatable Curtain (IC) – A New Head Protection System in Side Impacts"
[80] See additional discussion on the head-to-striking impact in Appendix B of this chapter.

Table V-70
Head Benefits, 50th Occupants, Head-to-Front of Striking Vehicle
Vehicle-to-Vehicle Side Crashes, Front Occupant, Near Outboard Seating Positions

	MAIS 3	MAIS 4	MAIS 5	Fatality
Head-to-striking vehicle/others:	189	89	43	222
Effectiveness:	0.00%	0.00%	60.6%	100%
Benefits:	0	0	26	222

The benefits were re-distributed at a HIC of 458, which would be measured with a deployed air bag in head-to-striking vehicle in vehicle-to-vehicle side crashes, as shown below:

Table V-71
Summary of Head Benefits, 50th Occupants
Head-to-Front of Striking Vehicle, Vehicle-to-Vehicle Side Crashes

	AIS 3	AIS 4	AIS 5	Fatality
Benefits:	0	0	26	222
Redistribution:	21	5	0	0
Net Benefits:	-21	-5	26	222

The results in Table V-71 show that the 214-head bag would save 222 lives and prevent 26 AIS 5 head injuries. However, the redistribution of the benefits would result in 5 AIS 4 and 21 AIS 3 head injuries.

As for the head impacts with the vehicle interior components case in vehicle-to-vehicle side crashes, benefits were derived by applying the effectiveness rate to each injury level, as shown below:

Table V-72
Summary of Head Benefits, 50th Occupants
Head-to-Interior Components, Vehicle-to-Vehicle Side Crashes

	AIS 3	AIS 4	AIS 5	Fatality
Head Injuries:	159	74	34	121
Effectiveness:	85.36%	88.76%	93.55%	97.06%
Benefits:	136	66	32	117
Redistribution:	9	2	0	0
Net Benefits:	126	64	31	117

The results in Tables V-71 and -72 were combined to derive head benefits for occupants represented by a 50th percentile male test dummy in vehicle-to-vehicle/other side crashes, as shown below:

Table V-73
Head Benefits
Occupants Represented by 50th Percentile Male Test Dummy
Vehicle-to-Vehicle Side Crashes
Front, Near Outboard Seating Positions

	AIS 3	AIS 4	AIS 5	Fatality
Benefits:	106	59	57	339

The results in Table V-73 show that head air bags would save 339 lives and prevent 57 AIS 5, 59 AIS 4 and 106 AIS 3 head injuries, annually, for occupants represented by a 50th test dummy in vehicle-to-vehicle/others side crashes.

For the occupants represented by the SID-IIs 5th percentile test dummy in vehicle-to-vehicle/others side crashes, the target population is shown in Table V-74.

Table V-74
Vehicle-to-vehicle or Other Objects Target Population
(Adjusted with Minimum Air Bag Size, ESC, 201-Benefits & 5th Occupants)

Body Region	MAIS 3	MAIS 4	MAIS 5	Fatality
Head and Face	116	54	26	114
Thorax	515	121	3	160
Abdomen	3	15	11	32
Pelvis	65	0	0	15

Similar to the methodology used for the 50th population, the target population was separated into two groups: head impacts with the striking vehicle and head impacts with vehicle interior components, as shown in Table V-75.

Table V-75
Head Injuries, Occupants Represented by 5th Female Test dummy
Adjusted with ESC Benefits, FMVSS No. 201-Potetial Benefits, and Coverage

Head impact object	MAIS 3	MAIS 4	MAIS 5	Fatal
Head-impacts-w/-striking vehicle:	63	30	14	74
Head-impacts-w/-veh. interior components:	53	25	11	40
Total:	116	54	26	114

For the head impacts with the striking vehicle case, the previously derived effectiveness for the 50th percentile male test dummy, as a proxy[81], was applied to each injury target population, as shown in Table V-76.

Table V-76
Head Benefits for Occupants Represented by 5th Percentile Female Dummy
Head Impacts with Striking Vehicle Case
Vehicle-to-Vehicle/Others

	AIS 3	AI S 4	AIS 5	Fatal
Head Injuries:	63	30	14	74
Effectiveness[82]:	0%	0%	60.60%	100%
Benefits:	0	0	9	74
Redistribution:	7	2	0	0
Net Benefits:	-7	-2	9	74

[81] When a head impacts with a rigid object, whether a pole or the front of striking vehicle, at a vehicle delta-V of 20 mph, the resulting HIC scores would be very high, regardless of the height of occupants. In the pole tests, for example, average HIC scores of 14,242 and 11,534 were measured with the 50th dummy and the 5th female test dummy, respectively. Although the HIC measured with the 50th is higher (19%) than the HIC measured with the 5th, the injury risks associated with the HIC scores are virtually identical as shown below:

	HIC	**AIS 3**	**AIS 4**	**AIS 5**	**Fatal**
50th	14,242	0%	0%	0%	100%
5th	11,534	0%	0%	0%	100%

With deployed head air bags, both the 50th and 5th dummies exhibited similar HIC scores, as shown below:

	HIC	**AIS 3**	**AIS 4**	**AIS 5**	**Fatal**
50th	504	10.01%	2.62%	0.23%	0.01%
5th	508	10.19%	2.67%	0.23%	0.01%

The results in the tables above show that the 214-head bags are equally effective in preventing head injuries in head-to-rigid object impacts, regardless of the height of occupants. Accordingly, the use of 5th or 50th HIC scores would not affect the estimate.

[82] As discussed previously, the point estimate, which is based on HIC scores at a vehicle delta-V of 20 mph, would underestimate the head benefits by excluding the AIS 3 and 4 head/face injuries.

The results in Table V-76 show that the 214-head bags would save 74 lives and prevent 9 AIS 5 head/face injuries for occupants represented by a 5th female test dummy when the head impacts with the striking vehicle in vehicle-to-vehicle/others side crashes in a delta-V range of 12 –25 mph. However, the redistribution of the benefits would result in 2 AIS 4 and 7 AIS 3 head/face injuries.

As for the head impacts with the vehicle interior components case, for occupants represented by a 5th percentile female test dummy, in vehicle-to-vehicle side crashes, benefits were derived as shown in Table V-77.

Table V-77
Head Benefits for Occupants Represented by 5th Percentile Female Dummy
Head Impacts with Vehicle Interior Components Case
Vehicle-to-Vehicle/Others

	AIS 3	AI S 4	AIS 5	Fatal
Head Injuries:	53	25	11	40
Effectiveness:	85.36%	88.76%	93.55%	97.06%
Benefits:	45	22	11	39
Redistribution:	3	1	0	0
Net Benefits[83]:	42	21	10	39

The results in Table V-73 show that the FMVSS No. 214-head bags would save 39 lives and prevent 10 AIS 5, 21 AIS 4 and 42 AIS 3 head/face injuries for occupants represented by a 5th percentile female test dummy in vehicle-to-vehicle/others side crashes in a delta-V range of 12 –25 mph.

[83] All estimates have been rounded to the nearest integer.

The results in Tables V-76 and V-77 were combined to derive head benefits for occupants represented by a 5th percentile female test dummy in vehicle-to-vehicle/other side crashes, as shown below:

Table V-78
Head Benefits for Occupants Represented by
5th Percentile Female Dummy in Vehicle-to-Vehicle Side Crashes
Front, Near-side, Outboard Seating Positions

	AIS 3	AIS 4	AIS 5	Fatality
Benefits:	35	20	19	113

For all occupants in vehicle-to-vehicle/other side crashes, the results in Tables V-73 and -78 were combined, as shown in Table V-79.

Table V-79
Overall Head Benefits for All Occupants in Front, Near Side
Vehicle-to-Vehicle/Others Side Crashes

Occupants	AIS 3	AIS 4	AIS 5	Fatality
50th:	106	59	57	339
5th:	35	20	19	113
Total	141	78	76	452

The results in Table V-79 show that the FMVSS No. 214-head air bags would save 452 lives and prevent 76 AIS 5, 78 AIS 4 and 141 AIS 3 head/face injuries, annually, for occupants in front near-side outboard seating positions in vehicle-to-vehicle/others side crashes.

Chest (Vehicle-to-Vehicle/Others): For the chest injuries, the NHTSA MDB test results were used to derive the benefits.[84] The injuries by severity level are shown below:

[84] Although the chest deflections measured in the pole tests show a marginal improvement with thorax bags, the lower spine acceleration measurements show that thorax air bags are effective in reducing chest injuries. Thus, some of the vehicles failed to meet the lower spine acceleration requirements in the pole would be equipped with new or improved thorax air bags. In addition, the MDB test results show that thorax bags are effective in reducing chest deflection for both 50th and 5th percentile test dummies. Therefore, we assumed that the majority of future vehicles would be equipped with thorax air bags in front

Table V-80
Chest Injuries
Occupants Represented by 50th Percentile Male Test Dummy
Vehicle-to-Vehicle/Other Side Crashes, Front, Near-side

	MAIS 3	MAIS 4	MAIS 5	Fatal
Chest Injuries, 50th	1,544	364	8	480

The MDB test results show that an average chest deflection of 37 mm was measured without thorax bags. There is a 42% chance of AIS 3+ and a 16% chance of AIS 4 chest injuries at this deflection level. With deployed chest bags, an average chest deflection of 28 mm was measured, as shown below:

Table V-81
Thorax Bag Effectiveness
Occupants Represented by 50th Male Test Dummy
Vehicle-to-Vehicle/others Side Crashes

	Chest Deflection (mm)	Injury Risk		
		AIS 3+	AIS 4+	AIS 3
Without Bag:	37	42%	16%	26%
With Bag:	28	32%	11%	21%
Effectiveness:		23.61%	30.99%	19.05%

According to the target population, there were 1,544 AIS 3 and 852 AIS 4+ chest injuries. The effectiveness rates in Table V-81 show that thorax air bags would prevent 294 AIS 3 and 265 AIS 4+ chest injuries (including fatalities), annually. As discussed previously, we do not have the risk curves for AIS 4, AIS 5 and fatal chest injuries with respect to chest deflection. Therefore, for the estimate, the effectiveness score derived for the AIS 4+ was used for AIS 4, AIS 5 and fatal injuries, as shown below:

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outboard seating positions. Accordingly, for the chest benefit analysis for occupants in front seating positions, we used the thorax bag effectiveness for the MDB, although no vehicles failed the required chest deflection (for 50th)

However, for occupants in rear outboard seating positions, the agency does not require a pole test. In addition, there is no data that indicate that vehicle manufacturers would either install a new thorax bag or improve the vehicle structure, knowing that all vehicles met the MDB requirements. Therefore, chest benefits for occupants in rear seating positions were not estimated.

Table V-82
Chest Benefits
Occupants Represented by the 50th Percentile Dummy
Vehicle-to-Vehicle/others Side Crashes

	AIS 3	AIS 4	AIS 5	Fatal	Total
Chest Injuries:	1,544	364	8	480	
Effectiveness:	19.05%	30.99%	30.99%	30.99%	
Benefits:	294	113	3	149	558

The results in Table V-82 show that 149 lives would be saved and 3 AIS 5, 113 AIS 4 and 294 AIS 3 chest injuries would be prevented with thorax bags in vehicle-to-vehicle/others crashes. The injury prevented and lives saved were redistributed at a chest deflection of 28 mm (that would be expected with a deployed air bag at a lateral vehicle delta-V of 20 mph[85]). With this deflection, there is a 32% chance of AIS 3+ injury risk. In other words, the majority of the AIS 3+ injuries prevented would result in AIS 2, AIS 1 or no injuries. Since only AIS-3+ and AIS-4+ injury probability curves are available, we assumed that 32% of the AIS 3+ benefits result in AIS 3 injuries and the remaining 378 benefits are equally distributed among AIS 1 and AIS 2 chest injuries, as shown below:

Table V-83
Overall Chest Injuries Benefits
Occupants Represented by 50th Test Dummy
Vehicle-to-Vehicle/Others Side Crashes

	AIS 3	AIS 4	AIS 5	Fatal
Chest Injuries:	1,544	364	8	480
Effectiveness:	19.05%	30.99%	30.99%	30.99%
Benefits:	294	113	3	149
Redistribution:	180	0	0	0
Net Benefits:	114	113	3	149

The results in Table V-83 show that thorax air bags would save 149 lives and prevent 3 AIS 5, 113 AIS 4 and 114 AIS 3 chest injuries, annually.

[85] When measured with the 214 seating procedure with the ES-2re.

For the occupants represented by the SID-IIs 5th percentile test dummy for the vehicle-to-vehicle/others case, there were 515 AIS 3 and 284 AIS 4+ chest injuries in the target population, as shown below:

Table V-84
Chest Injuries
Occupants Represented by 5th Female Dummy
Vehicle-to-Vehicle/others Side Crashes

	MAIS 3	MAIS 4	MAIS 5	Fatal
Chest Injuries, 5th:	515	121	3	160

The 5th female test dummy is capable of measuring not only lower spine acceleration but also chest deflection. The MDB test results show that an average chest deflection of 19.1 mm was measured without air bags and an average deflection of 17.1 mm with deployed air bags. For the spine acceleration, an average spine acceleration of 53 g was measured without air bags and 42 g with bags. The measurements, the associated injury risks and bag effectiveness rates are shown below:

Table V-85
Chest Deflection
Occupants Represented by 5th Female Dummy
Vehicle-to-Vehicle/others Side Crashes

	Deflection	AIS 3+	AIS 4+	AIS 3
Without Bag:	19.1 mm	5.20%	0.785%	4.42%
With Bag:	17.1 mm	3.88%	0.579%	3.30%
Effectiveness:		25.37%	26.24%	25.21%
Injuries:			284	515

Table V-86
Lower Spine Acceleration
Occupants Represented by 5th Female Dummy
Vehicle-to-Vehicle/others Side Crashes

	Lower Spine Acceleration	AIS 3+	AIS 4+	AIS 3
Without Bag:	53 g	44.07%	20.62%	23.46%
With Bag:	42 g	38.18%	16.94%	21.23%
Effectiveness:		13.38%	17.82%	9.47%
Injuries:			284	515

The results in Table V-85 show that thorax air bags would save 204 AIS 3+ chest injuries. Among these injuries prevented, 130 would be AIS 3 injuries. When the lower spine acceleration results are considered, Table V-86 show that 107 AIS 3+ would be saved by thorax bags in vehicle-to-vehicle/others side crashes. The AIS 3+ benefit estimates show that both measurements (deflection and lower spine-g) would result in substantial AIS 3+ benefits. Since both chest deflection and lower spine acceleration measurements show that thorax bags would provide benefits and the use of chest deflection would provide a better estimate (as discussed previously), we made the estimate based on the chest deflection measurements. The estimated benefits are shown below:

Table V-87
Chest Benefits
Occupants Represented by 5th Female Test Dummy
Vehicle-to-Vehicle/Others Side Crashes

	AIS 3	AIS 4	AIS 5	Fatal	Total*
Chest Injuries:	515	121	3	160	
Effectiveness:	25.21%	26.24%	26.24%	26.24%	
Benefits:	130	32	1	42	204

*The estimated have been rounded to the nearest integer.

With deployed air bags, an average chest deflection of 17.1 mm was measured in the MDB tests. At this deflection level, there is a 3.88 % chance of AIS 3+ injury risk. For the analysis, we assumed that 3.88 % of the 204 injuries result in AIS 3, as shown below:

Table V-88
Chest Benefits
Occupants Represented by 5th Female Test Dummy
Vehicle-to-Vehicle/Others Side Crashes

	AIS 3	AIS 4	AIS 5	Fatal
Chest Injuries:	515	121	3	160
Effectiveness:	25.21%	26.24%	26.24%	26.24%
Benefits:	130	32	1	42
Redistribution:	8	0	0	0
Net Benefits:	122	32	1	42

The results in Table V-88 show that for occupants represented by a 5th female test dummy thorax air bags would save 42 lives and prevent 1 AIS 5, 32 AIS 4 and 122 AIS 3 chest injuries, annually, in vehicle-to-vehicle/others side crashes.

The results in Tables V-83 and -88 were combined to derive the net benefit for chest injuries in vehicle-to-vehicle/others crashes for all occupants, as shown below:

Table V-89
Chest Injury Benefits
All Adult Occupants, Front, Near-side
Vehicle-to-Vehicle/Others Side Crashes

Occupants	AIS 3	AIS 4	AIS 5	Fatality
50th Occupants:	114	113	3	149
5th Occupants:	122	32	1	42
Total	236	144	3	191

The results in Table V-89 show that thorax air bags would save 191 lives and prevent 3 AIS 5, 144 AIS 4 and 236 AIS 3 chest injuries, annually, in vehicle-to-vehicle/others side impact crashes.

Abdomen: The MDB test results show that an average abdominal force of 1,466 N was measured without thorax bags and all vehicles met the required 2,500N. At the 1,466 N force level, there is a less than 1% risk of AIS 4+. With thorax bags, an average abdominal force of 690 N was measured. As discussed, according to the probability of AIS 4+ abdominal injury based on Walfisch and Viano, the reduction in abdomen force would be insignificant in reducing AIS 4+ non-fatal and fatal injuries. With the 1,466 N force measured, there is 0.21% of AIS 4+ injury risk, whereas at the 690 N-force level, there is less than 0.04% of AIS 4+ injury risk. The corresponding injury risks show that it would be extremely rare to have AIS 4+ injuries at these force levels. However, the real world crash data show that approximately 17% of fatalities are from abdominal injuries (146/869 = 17%, MAIS 1+, considering only the fatalities in the target population[86]). Regarding AIS 3 abdominal injuries, the test data show that there is a 5% chance of AIS 3 injuries without thorax bags. The measurements with thorax air bags show that bags would reduce the risk substantially, by about 5 times. Although, hypothetically, an effectiveness rate[87] could be derived based on the AIS 4+ injury risks, as discussed above, AIS 4+ abdomen benefit estimation was not performed. The AIS 3 benefits are shown below:

Table V-90
AIS 3+ Abdomen Benefits
Occupants Represented By 50th Male Test Dummy

	AIS 3	AIS 4	AIS 5	Fatal
Injuries:	10	45	32	96
Effectiveness:	80.02%	0%	0%	0%
Benefits:	8	0	0	0

[86] For additional discussion, see the target population section.

[87] Abdominal effectiveness rates, occupants represented by a 50th percentile male test dummy, in vehicle-to-vehicle/others side crashes:

Abdominal Force (N)	AIS 3+	AIS 4+	AIS 3
1,466	5.15%	0.21%	4.94%
690	1.03%	0.04%	0.99%
Effectiveness	80.06%	80.85%	80.02%

For the occupants represented by the SID-IIs 5th percentile test dummy, as discussed, benefit estimation for the abdomen was not made.

<u>Pelvis</u>: For occupants represented by the 50th dummy, The MDB test results show an average pelvic force of 2,351 N without thorax bags and an average force of 1,864 N with thorax bags. All vehicles tested met the minimum performance requirement of 6,000 N, as shown below:

Table V-91
Pelvis Benefits
Occupants Represented By 50th Test Dummy
Vehicle-to-Vehicle Side Impact Crashes

	AIS 3	AIS 4	AIS 5	Fatal
Injuries:	196	0	0	44
Effectiveness:	41%	41%	41%	41%
Benefits:	81	0	0	18

For the occupants represented by the SID-IIs 5th percentile test dummy, the benefits are shown below:

Table V-92
Pelvis Benefits
Occupants Represented By 5th Female Test Dummy
Vehicle-to-Vehicle Side Impact Crashes

	AIS 3	AIS 4	AIS 5	Fatal
Injuries:	65	0	0	15
Effectiveness:	95.7%	95.7%	95.7%	95.7%
Benefits:	63	0	0	14

In summary, for the vehicle-to-vehicle/others, the analysis shows 675 lives would be saved and 80 AIS 5, 223 AIS 4 and 529 AIS 3 injuries would be prevented, annually, when the proposed oblique pole test with the ES-2re and SID-IIs is adopted, as shown in Table V-93.

Table V-93
Overall Benefits[88] for All Adult Occupants, Near Front
Vehicle-to-Vehicle/Others in Side Crashes

Body region	AIS 3	AIS 4	AIS 5	Fatality
Head:	141	78	76	452
Chest:	236	144	3	191
Abdomen:	8	0	0	0
Pelvis:	144	0	0	32
Total	529	223	80	675

Occupants in far side outboard and center seating positions:

According to a recent study[89] done by Kahane, statistical analyses of FARS and GES data show significant reductions of fatality risk for head curtain plus torso bags in far-side impacts to passenger cars for unrestrained occupants and for belted drivers riding alone in the front seat by 24 percent. With torso bags only, the bags reduce fatality risk by 12 percent. For unbelted occupants, Dr. Kahane found that, "With the data available at this time, it is reasonable to conclude that side air bags are beneficial for unrestrained occupants in far-side impacts; the effect for belted occupants, if any, is likely to be small. Because there is no compelling evidence to the contrary, we may further assume, for the time being, that the percentage fatality reduction for unrestrained occupants in far side impacts is the same as the reduction for all occupants in nearside impacts." In the analyses, with the limited crash data available to date, we didn't find consistently significant far-side fatality reduction for (1) LTVs (with any type of side air bags), (2) torso bags alone or torso/head combination bags (i.e., combo) in cars, or (3) belted occupants (when somebody sits between them and the far-side). According to 2004

[88] All estimates have been rounded to the nearest integer.
[89] See Appendix F for additional discussion.

FARS data, a total of 1,441 fatalities occurred, annually. These fatalities are approximately 15.5% of all fatalities that occurred in side crashes, as shown below:

	Fatalities
No Rollover, Adult, Far Side Impact, Unbelted – Observed Fatalities:	1,441
Observed Fatalities Adjusted for ESC:	1,274
Assumed percent of passenger cars in the fleet:	50%
Head air bags installation rate observed in MY 2004:	9.7%
Head air bags installation rate in MY 2011:	93.43%
Effectiveness rate for far-side occupants:	24%

$$Potential\,Fatality = \frac{Observed\,Fatality}{\left[1-\left(Installation\ rate\ in\ potential\ crashes, 2004\right)*\left(Effectiveness\ rate\right)\right]}$$

Observed Fatality: 637 (1,274*0.5 = 637)

Potential Fatality: 652

Fatality Prevented = (Potential Fatality)*(Effectiveness rate)

Fatality Prevented: 157

Incremental Benefits = (Fatality Prevented)*(1- installation, MY2011*Passing rate)

Incremental Benefits: 40

In summary, if the FMVSS No. 214-vehicles were equipped with head and thorax bags, accordingly, a total of 40 lives would be saved in far side impacts, annually, when MY 2011 side air bag sales are used as a baseline.[90]

[90] Occupants in 3rd+ seats: Based on MY 2000 sales (the last year the agency studied vehicle sales by seating position), virtually no passenger cars and 22 percent of light trucks have 3 or more seats (mini-vans, some SUVs, and full size vans). We are currently assuming that passenger cars and light trucks will each have 50 percent of all light vehicle sales, thus about 11 percent (22%*.5) of all light vehicle sales will have 3 or more seats.

Regarding fatalities in side impact, in the case of adults in non-rollover as a primary event, there were 17 fatalities in the 3rd, 4th, or 5th rows. In comparison, in the same types of non-rollover side impacts there

C. Benefit Summary

(1) Vehicles Equipped with HPS: The benefit estimate was based on an assumption that the vehicles used for the target population were not equipped with HPS, as shown in Table V-94.

Table V-94
Benefits of Head and Thorax/Side Air Bags
All Adult Occupants in All, Front, Near Side Crashes

Crashes	AIS 3	AIS 4	AIS 5	Fatality
Vehicle-to-Pole/Tree	-7	22	15	124
Vehicle-to-vehicle/Others	529	223	80	675
Total:	522	245	95	799

Since some of the vehicles were indeed equipped with head and/or thorax air bags, the estimated benefits (in terms of lives saved and injuries prevented) were further adjusted with the number of vehicles equipped with head and thorax bags and also the compliance rate of the bags (i.e., meeting the requirements). For the adjustment, individual bag type was not considered; rather it was assumed that vehicles are equipped with the hypothetical production HPS (as discussed in the analysis) regardless of vehicle model or type. In addition, it was assumed that performance of future HPS is same as the production HPS used for the analysis. In other words, the compliance rate determined in the pole tests remains unchanged.

were 8,570 adult fatalities in all rows. The real world crash data show that the 3+ seats make up 0.2 percent of the fatalities in that population (17/8,570 = 0.002).

For the compliance rate (i.e., passing rate for the proposed pole requirements), each injury criterion was considered based on the oblique pole test results, as shown in Table V-95.

Table V-95
Oblique Pole Test Compliance Rate
With 214-Seating Procedure

Vehicle	Head		Chest		Abdomen		Pelvis	
	50th	5th	50th	5th	50th	5th	50th	5th
2005 Toyota Corolla	P	P	F	P	P	N/A	P	N/A
2005 VW Jetta	P	P	P	P	P	N/A	P	F
2001 Saturn Ion	P	F	F	F	P	N/A	P	F
2004 Honda Accord	P	P	N/A	P	N/A	N/A	N/A	F
2005 Beetle Convertible	P	N/A	P	N/A	P	N/A	P	N/A
2005 Saab 9-3 Conv.	P	N/A	P	N/A	P	N/A	P	N/A
2005 Ford Five-Hundred	P	F	P	F	F	N/A	P	F
2004/05 Toyota Sienna	P	F	F	P	P	N/A	P	F
2005 Subaru Forester	F	P	P	P	P	N/A	P	P
2005 Honda CRV	P	P	F	P	P	N/A	P	P
2005 Chevy Colorado	P	P	F	F	F	N/A	P	F
2005 Ford Expedition	P	F	P	F	F	N/A	P	F
1999 Volvo S80	P	N/A	F	N/A	P	N/A	P	N/A
2000 Saab 9-5	P	N/A	F	N/A	P	N/A	P	N/A
2004 Toyota Camry	P	N/A	P	N/A	P	N/A	P	N/A

Table V-96
Oblique Pole Test Compliance Rate
With 214-Seating Procedure

	Head	Chest	Abdomen	Pelvis
Passing Rate:	80.00%	56.00%	80.00%	70.83%

Vehicles equipped with head and side air bags and its distribution are shown in Tables V-97 and -98.

Table V-97
Absolute Values for Passenger Cars and Light Trucks for All Body Types

	1999	2000	2001	2002	2003	2004	2005	Total
Thorax only	1,085,352	1,723,385	1,451,166	2,477,771	2,025,099	1,618,914	1725017	12,106,703
AC+Th	98,241	126,436	664,973	990,382	1,603,937	2,595,269	3760391.6	9,839,630
Combo	251,887	783,171	1,278,710	1,250,147	1,338,557	810,456	1298437.1	7,011,365
AC only	0	0	38,328	170,081	398,805	616,204	651150.31	1,874,568
ITS+Th	122,973	155,675	198,895	213,726	252,647	359,870	228650	1,532,436
Total	1,558,453	2,788,667	3,632,072	5,102,107	5,619,044	6,000,713	7,663,646	32364703

Table V-98
Distribution of Head and Thorax Air Bags (up to 2005 estimated sales)

	1999	2000	2001	2002	2003	2004	2005	Average
Head Protection Only	0.00%	0.00%	0.23%	0.99%	2.22%	3.61%	3.67%	1.55%
Thorax Protection Only	6.49%	9.81%	8.76%	14.38%	11.26%	9.48%	9.72%	10.01%
Head and Thorax Protection	2.83%	6.06%	12.93%	14.25%	17.76%	22.04%	29.78%	15.21%
Total	9.32%	15.88%	21.92%	29.62%	31.24%	35.12%	43.17%	26.77%

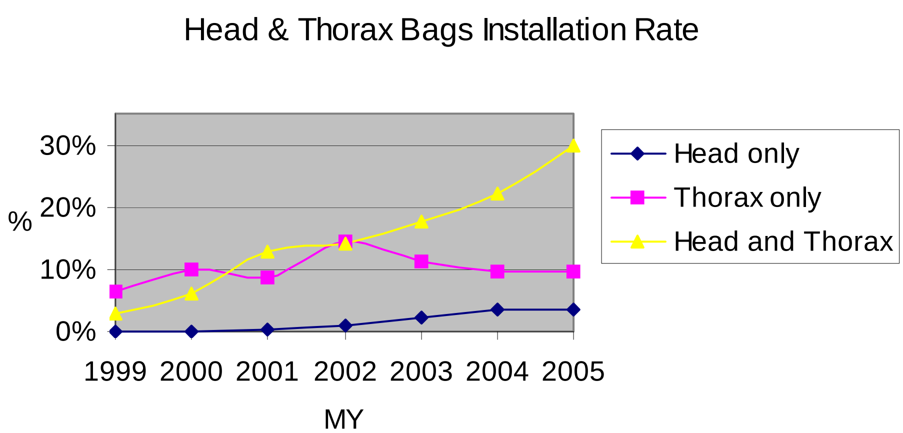

Figure V-6. Distribution of Head and Thorax Bags vs. Model Year

In addition, the benefits resulting from the vehicle-to-pole and vehicle-to-vehicle/others were adjusted with the number of vehicles that will be equipped with head & side air bags[91], passing rate and the percent of 50th occupants, as shown in Tables[92] V-99 to -101. [93]

[91] Based on the projected 2011 side air bag sales data.
[92] All estimates have been rounded to the nearest integer.
[93] For the adjustment, the pass/fail rates resulting from the oblique pole tests were used, due to limited data. For the head benefit adjustment, the use of the pole (compliance, pass/fail) data would be a reasonable proxy since a head bag failed in the pole would not provide a head protection when a head impacts with the front of a striking vehicle in side crashes. For the chest benefit adjustment, some of the chest bags failed during the pole tests (56% passing rate) whereas none of the bags failed in the MDB (100% passing rate). The use of the pole pass/fail data would result in an overestimate. Thus, the use of the pole chest pass/fail rate would result in a slightly higher additional chest benefits estimate [(1 - (100%)x26.32%) vs. (1 – (56%)x26.32%)].

Table V-99
Additional Lives Saved and Injuries Prevented
Vehicle-to-Pole/Tree Side Crashes, 12 –25 mph
Front, Near Side

Head:	AIS 3	AIS 4	AIS 5	Fatal
Benefits	-5	13	15	122
Additional Benefits	-1	3	4	31
Chest:	AIS 3	AIS 4	AIS 5	Fatal
Benefits	-2	9	0	2
Additional Benefits	-1	5	0	1
Abdomen:	AIS 3	AIS 4	AIS 5	Fatal
Benefits	0	0	0	0
Additional Benefits	0	0	0	0
Pelvis:	AIS 3	AIS 4	AIS 5	Fatal
Benefits	0	0	0	0
Additional Benefits	0	0	0	0
	AIS 3	AIS 4	AIS 5	Fatal
Total Additional Benefits	-2	9	4	32

Table V-100
Additional Lives Saved and Injuries Prevented
Vehicle-to-Vehicle/Others Side Crashes, 12 –25 mph

Head:	AIS 3	AIS 4	AIS 5	Fatal
Benefits	141	78	76	452
Additional Benefits	36	20	19	114
Chest:	AIS 3	AIS 4	AIS 5	Fatal
Benefits	236	144	3	191
Additional Benefits	137	84	2	111
Abdomen:	AIS 3	AIS 4	AIS 5	Fatal
Benefits	8	0	0	0
Additional Benefits	3	0	0	0
Pelvis:	AIS 3	AIS 4	AIS 5	Fatal
Benefits	144	0	0	32
Additional Benefits	42	0	0	9
	AIS 3	AIS 4	AIS 5	Fatal
Total Additional Benefits	218	103	21	235

Table V-101
Total Additional Lives Saved and Injuries Prevented*
By Body Region, 12 –25 mph

Head	AIS 3	AIS 4	AIS 5	Fatal
Target Population, Adjusted:	485	276	158	580
Additional Benefits:	34	23	23	145
Chest	AIS 3	AIS 4	AIS 5	Fatal
Target Population, Adjusted:	2,180	600	11	663
Additional Benefits:	136	89	2	112
Abdomen	AIS 3	AIS 4	AIS 5	Fatal
Target Population, Adjusted:	14	60	43	127
Additional Benefits:	3	0	0	0
Pelvis	AIS 3	AIS 4	AIS 5	Fatal
Target Population, Adjusted:	262	0	0	58
Additional Benefits:	42	0	0	9
	AIS 3	AIS 4	AIS 5	Fatal
Total:	216	112	25	267

* The numbers were rounded to the nearest integer.

The estimate for the complete ejection case is based on 100% installation of the 214-curtain bag in the fleet.

Summary of Overall Lives Saved and Injuries Prevented: For occupants in front near side outboard seating positions, the benefits analysis show that torso plus head air bags in cars and LTVs would save 799 lives[94], annually, for occupants in front near outboard seating positions. When the benefits are adjusted with the bag distribution and compliance rate, 267 lives would be saved and 352 serious injuries would be prevented, annually, as shown below:

[94] As discussed in the target population section, the ESC potential benefits and the 201-benefits were excluded from the target population.

Table V-102
Summary of Additional Benefits* for Each Injury Level
Front, Near Side Outboard Seating Positions
(If all vehicles are equipped with curtain or ITS 100% distribution rate, in MY 2011)

Crashes	AIS 3	AIS 4	AIS 5	Fatality
Vehicle-to-pole/tree:	-2	9	4	32
Vehicle-to-Vehicle/Others:	218	103	21	235
Net Benefits:	216	112	25	267

* All estimates have been rounded to the nearest integer.

<u>Surveillance of Current Head and Side Air Bags</u>: August 2003, IIHS published[95] a statistical analysis based on driver only fatalities in passenger cars[96] of model years 1997-2002 in calendar year 1999-2001 FARS data. They compared nearside fatalities (initial impact = 8-10:00) in cars equipped with side air bags to nearside fatalities in cars not equipped with side air bags, relative to control groups of purely frontal or rear-impact fatalities (12:00 or 6:00). All vehicles in the analyses are equipped with frontal air bags at the driver and right front seats. Based on a rather small sample, the analysis showed a statistically significant 45 percent reduction in nearside fatalities for head+torso air bags, and a nonsignificant, but promising 11 percent reduction for torso air bags alone.

Subsequent to the initial study, Kahane performed a study on the effect of side air bags on fatalities and ejection in side cashes.[97] Kahane reported that torso bags plus head protection in passenger cars reduces the fatality risk of near-side front-seat occupants in single- and multi-vehicle crashes by a statistically significant 24 percent (90 percent confidence bound, 4 to 42 percent). In addition, he reported that torso bags alone would

[95] "Efficacy of Side Airbags in Reducing Driver Deaths in Driver-Side Collisions", Elisa R. Braver and Sergey Y. Kyrychenko, Insurance Institute for Highway Safety, August 2003.
[96] Vans and SUV's with side air bags were not included in the analysis since there were so few cases in the FARS files. There were no cases with side air bags in pickup trucks.
[97] The summary of the study is provided in Appendix F.

reduce the fatal risk by 12 percent. The data also show a statistically significant fatality reduction in LTVs and suggest that the effectiveness may be the same as in cars. For near-side crashes, he found that the available data do not show a difference in fatality reduction between the two types of head air bags: curtains (or ITSs) and torso/head combination bags (i.e., Combo).[98]

Lives Saved by Side Impact Protection in Calendar Year 2003: According to a report titled[99], "An Evaluation of Side Impact Protection, FMVSS 214 TTI(d) Improvements and Side Air Bags," in calendar year 2003, 9,107 drivers and passenger were fatalities in cars and LTVs whose initial and/or principal impact was a side impact. If none of these cars and LTVs had been equipped with side air bags, and if all the cars had impact performance characteristics of the pre-1986 fleet, fatalities would have increased to 9,979. Thus TTI(d) reduction in cars and side air bags in cars and LTVs saved an estimated 872 lives in 2003. Among the 872 lives saved in 2003, torso plus head air bags saved 41 lives, torso bags saved 27 lives and head curtain only saved 1 life, as shown below:

[98] Docket No. NHTSA-2007-27588
[99] A report titled "An Evaluation of Side Impact Protection," January 2007, Charles J. Kahane, National Center for Statistics and Analysis, NHTSA

Table V-103
Lives Saved By Side Impact Protection in Calendar Year 2003
(Real World Crash Data)

Side Air Bags in Cars and LTVs		Lives Saved	% of total
	Torso Plus Head air Bags	41	59%
	Torso Bags only	27	39%
	Head Curtain only	1	2%
	Subtotal:	69	100%
TTI(d) Improvement by Structures and Padding in Cars			
	In FMVSS 214-certified	569	
	Voluntary improvements in 1986-1996 non-certified cars	234	
	Subtotal:	803	
	Total: Lives saved in 2003:	872	

Lives Hypothetically Savable in 2003: The report states that an estimated 2,934 lives would have been saved in calendar year 2003 if every car and LTV had been equipped with head curtains plus torso bags and if every car had been equipped with side structures and padding characteristic of FMVSS No. 214-certified vehicles. In other words, if all cars and LTVs on the road had been equipped with head curtains plus torso bags and if every car had post-1996 side impact performance, there would been only 7,045 fatalities. The combination of TTI(d) reduction and head curtains plus torso bags could have save an estimated 2,934 lives per year (9,979 – 7,045) if it had been installed in the entire on-road fleet by 2003. The number of side impact fatalities that would happened in 2003 if every car and LTV on the road had been so equipped is 2,934 fewer than the number that would have occurred if no vehicles at all had side air bags and if all cars still had TTI(d) performance characteristic of 1985 and earlier model years. The hypothetical benefits included 1,791 lives savable by head curtains plus torso bags in cars and LTVs and 1,143 lives savable by TTI(d) improvements in cars.

The agency believes there could be significant additional benefits that can be gained in the future by adding a rollover sensor, covering the window opening further, extending window curtains down to the windowsill area, and reducing ejection in rollover crashes.

D. Discussion

(1) Occupants in Rear Outboard Seating Positions: A curtain (AC) type head air bag system has a rather large surface area in its deployed stage. Curtain air bags are usually attached to the C-pillar and A-pillar and often cover not only front but also rear side window opening. Thus, it is likely that an AC HPS designed to meet the performance requirements will provide some protection for occupants in rear outboard seating positions if the air bag sensors are designed to deploy when the vehicle is impacted at the rear door or the C-pillar.

According to 2000 –2004, NASS CDS annualized crash data for rear outboard MAIS 1+ injuries, 1,658 injuries occurred annually in vehicle-to-pole and vehicle-to-vehicle/others crashes. Among these injuries, 217 are head & facial AIS 3+ injuries, as shown in Table V-104.

Table V-104
Head & Face Injuries of Rear Near-side Outboard Occupants
2000-2004 NASS CDS, 2004 FARS, 2004 GES
Damaged Lateral Zone: P, Y, Z with DOF in 1-5, 7-11
Lateral Delta-V of 12 –25 mph

Injury	MAIS 3	MAIS 4	MAIS 5	Fatal	Total
Head & Face:	147	42	0	28	217
Chest:	24	45	61	5	135

As discussed, curtain air bags would prevent some of rear occupant head injuries in side crashes. For the analysis, we assumed that curtain air bags are big enough to protect occupants represented by a 5th percentile female test dummy in PDOF of 2-3 and 9-10 o'clock positions.

For the analysis, similar to the front occupants, the rear occupant AIS 3+ injuries were adjusted with the ESC and FMVSS No. 201-benefits, as shown in Tables V-105 and -106.

Table V-105
Occupants[100] in Rear Outboard Seating Positions
Vehicle-to-Pole/Tree Side Crashes

Body Region	MAIS 3	MAIS 4	MAIS 5	Fatal
Head & face	48	0	0	2
Chest	0	0	0	0

Table V-106
Occupants in Rear Outboard Seating Positions
Vehicle-to-Vehicle/Others Side Crashes

Body Region	MAIS 3	MAIS 4	MAIS 5	Fatal
Head & face	62	38	0	19
Chest	22	41	56	4

<u>Head benefits</u> (rear, near-side): If all passenger cars and LTVs were equipped with curtain air bags, curtain air bag would save 23 lives and 83 serious head injuries for occupants in rear outboard seating positions[101], as shown in Table V-107.

Table V-107
<u>Head</u> Additional Benefits
Rear Occupants in Side Crashes

Crash	AIS 3	AIS 4	AIS 5	Fatal
Vehicle-to-Pole/Tree:	41	0	0	2
Vehicle-to-Vehicle/Others:	15	11	0	19
Total:	56	11	0	21

[100] For the impact direction and the bag coverage area, we used the same approach as the front. That is, the bags would affect 94% of the injuries.
[101] See Appendix B for detailed derivation used.

Chest Benefits: In the MDB tests, none of the vehicles were equipped with rear thorax bags[102]. The MDB test results show that all dummies in rear outboard seating positions met the chest requirements, as shown below:

Table V-108
Rear Occupants
50th Test Dummy Chest Deflection Measurements MDB Test

	Average	Std. Dev.	Max.	Min.
Chest Deflection without thorax bag	21 mm	8	29 mm	5 mm
Chest Deflection with thorax bag	N/A	N/A	N/A	N/A
Chest Deflection, if failed	All pass	All pass	All pass	All pass
Chest Deflection, if met requirement	21 mm	8	29 mm	5 mm

Table V-109a
Rear Occupants
5th Test Dummy Chest Deflection Measurements MDB Test

	Average	Std. Dev.	Max.	Min.
Chest Deflection without thorax bag	39 mm	9	49 mm	24 mm
Chest Deflection with thorax bag	N/A	N/A	N/A	N/A
Chest Deflection, if failed	N/A	N/A	N/A	N/A
Chest Deflection, if met requirement	N/A	N/A	N/A	N/A

Table V-109b
Rear Occupants
5th Test Dummy Lower Spine Acceleration Measurements, MDB Test

Lower Spine Acceleration	Average	Std. Dev.	Max.	Min.
Without thorax bag	57 g	12	73 g	42 g
With thorax bag	N/A	N/A	N/A	N/A
When failed	All pass	All pass	All pass	All pass
When met requirement	57 g	12	73 g	42 g

Since all dummies in rear seating positions met the chest requirements, we did not estimate benefits for the chest.[103]

Abdominal (in the rear): The target population shows no MAIS 3+ injuries. Accordingly, no benefit estimate was made.

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[102] Accordingly, the bag effectiveness was not derived for occupants in the rear.

[103] In the poles tests, some of dummies in the driver seat failed the chest requirements. The pole test results show that vehicle manufacturers would improve the vehicles by installing thorax air bags in the front. The MDB test results show that thorax bags are beneficial in reducing chest injuries, although none of the tested vehicles failed the requirements. We note that the 5th measurements show a very high chest deflection. Nevertheless, the test dummy met the requirement and there is no indication that vehicle manufacturers would install thorax air bags. Thus, we didn't estimate benefits for the chest.

Pelvis: During the MDB test, some of the vehicles failed the 5th pelvis force requirement of 5,525 N. It shows that the minimum pelvis force requirement would prevent 5 AIS 3 pelvic injuries,[104] annually.

The overall rear occupants in near-side outboard seating positions are shown below:

Table V-110
Overall Rear Occupant Benefits
12 –25 mph Side Crashes

Occupant	AIS 3	AIS 4	AIS 5	Fatal
50th	42	8	0	16
5th	19	3	0	5
Total[105]	61	11	0	21

For the additional benefits for occupants in rear near-side seating positions, we assumed a 75% passing rate for the pelvis since 6 out of 8 vehicles met the 5th pelvis requirement in the MDB tests. In addition, we assumed that curtain bags would have the same passing rate (80%) for both front and rear near-side occupants. The additional benefits for rear near-side occupants are shown below:

Table V-111
Overall Additional Rear Occupant Benefits*
12 –25 mph Side Crashes

	AIS 3	AIS 4	AIS 5	Fatal
Benefits	15	3	0	5

* The benefit numbers were are rounded to the nearest integer

[104] For the 5th pelvis:

	Pelvis Force (N)	AIS 2+
"Exceed"	6,737	50.68%
"Met"	3,303	3.91%
Effectiveness:		92.28%

	AIS 3	AIS 4	AIS 5	Fatal
Injuries:	5	0	0	0
Benefits:	5	0	0	0

[105] The benefit numbers are rounded to the nearest integer.

The results in Table V-111 show that the FMVSS No. 214-curtain air bags would save 5 additional lives and prevent 19 non-fatal serious injuries for occupants in rear outboard seating positions.

(2) Air bag Bottoming-Out Speed: The agency has tested both the combination head/thorax air bag and the separate window curtains with thorax air bags at 18 mph perpendicular and 20 mph oblique pole tests. In addition to the 18 mph and 20 mph tests, the agency tested a curtain head air bag in a 30 mph pole test. An analysis of the 30mph pole test and the ITS tested at a high speed (31.69 mph, see Appendix B for detailed discussion) shows that the bottoming out speed is strongly affected by bag design. The analysis shows that the ITS, which is thicker than a typical curtain air bags, would bottom out at a delta-V range of 25 – 30 mph, whereas the 30 mph pole test results show that a curtain would bottom out at a vehicle delta-V range of 20 –25 mph. In the Final Regulatory Impact Analysis, we are assuming that the device has full effectiveness in the 12 to 25 mph vehicle delta-V range, regardless of body region (i.e., head, chest, etc.). Although we believe that the 12 –25 mph is a reasonable average range based on the high speed pole and sled tests, we don't know how much difference there might be between manufacturer's designs.

(3) Crashes Involving Rollover: Rollover is a complex event, heavily influenced by vehicle properties, driver and road characteristics. Unlike other vehicle crashes, NASS and FARS databases do not report vehicle delta-Vs in rollovers (the number of rolls is reported), although they provide the number of fatal and nonfatal injuries resulting from

rollover incidents. While laboratory test results are available for rollover events, they are based on a specific test speed in a controlled test environment. (The test results often include injury levels, such as HIC and chest deflection, and the number of quarter turns that the subject vehicle turned during a rollover test.)

Regarding effectiveness of side/head air bags in rollover crashes, NHTSA and Simula Automotive Safety Devices conducted a joint research program to evaluate the effectiveness of the ITS in mitigating ejection during rollover crashes. Under the research program, a series of FMVSS No. 208 dolly rollover tests were performed using one 1993 and two 1994 Ford Explorers. In this test, the vehicle is held tilted at an angle of 23 degrees and is slid in a transverse direction along the test track. The dolly has an initial velocity of 30 mph and is rapidly decelerated to initiate the vehicle rollover. Each vehicle was equipped with ITS devices for both outboard seating positions. The doors were locked and windows rolled down prior to testing. For the first two tests, the unbelted Hybrid-III test dummies were positioned in the front seating positions. For the third test, the passenger side dummy was restrained with a lap/shoulder belt while the driver side dummy remained unrestrained. The dummies were instrumented with tri-axial accelerometers in the head, chest and pelvic, chest deflection potentiometer, and a Hybrid III neck transducer which measures axial tension and compression, anterior-posterior shear and bending moment, and lateral shear and bending moment. The test results show low HIC scores with the deployed head air bags (under 100).

One of the unique characteristics of tripped rollover events is that occupants are in motion prior to the initial (vehicle) impact. Consequently, it is quite feasible that the head of an unbelted occupant moves through a vehicle's open side window prior to the initial impact. Since side air bags are designed to deploy upon an impact, it is suspected that head/side air bags do not yield significant benefits in rollover crashes without sensors specifically designed for rollover events.

(4) Driver vs. Front Outboard Passenger: According to the 1997 – 2001 CDS, annualized, front outboard MAIS 1+ occupant injuries in non-rollover nearside side impacts with a lateral delta-V range of 12 – 25 mph, approximately 74% and 26% of all front occupant fatalities in side crashes were from drivers and the front outboard passengers, respectively. Since the majority of vehicles would be equipped with the identical head/thorax air bag systems for the driver and front passenger sides, the expected head and thorax (additional) benefits would be proportional to the fatality rate from these seating positions. According to the fatality distribution rates above, approximately 198 drivers and 69 front nearside outboard passengers would be saved, as shown below:

Table V-112
Driver and Front Near-side Outboard Passengers
Additional Lives Saved by Curtain and Thorax Air Bags
(if all vehicles are equipped with curtain and thorax air bags, w/ MY 2011 sales)

	AIS 3	AIS 4	AIS 5	Fatality
Overall:	216	112	25	267
Driver:	160	83	19	198
Front Passenger:	56	29	6	69

F. Benefits vs. Air Bag System

Since vehicle manufacturers could use different types of head and thorax air bag systems to comply with the requirements, the overall benefits would be affected by air bag type. We estimated benefits for three different systems for occupants in near-side seating positions: the combination head/thorax air bags with two sensors, the window curtain + thorax air bags with two sensors and the window curtain + thorax air bags with 4 sensors, as shown in Tables V-113 thru –115.

Table V-113
Combination Head/Thorax Side Air Bag with Two Sensors

Occupants	Crash	AIS 3	AIS 4	AIS 5	Fatal
Front, Near	Vehicle-to-Pole	-2	9	4	32
Front, Near	Vehicle-to-Vehicle	218	103	21	235
	Total Benefit	216	112	25	267

Table V-114
Window Curtain + Thorax Air Bags with Two Sensors

Occupants	Crash	AIS 3	AIS 4	AIS 5	Fatal
Front, Near	Vehicle-to-Pole	-2	9	4	32
Front, Near	Vehicle-to-Vehicle	218	103	21	235
Rear, Near	Vehicle-to-Vehicle	5	3	0	5
Far Side*					40
	Total Benefit	221	115	25	311

* Due to limited data, only fatal benefits were derived.

Table V-115
Window Curtain + Thorax Air Bags with Four Sensors

Occupants	Crash	AIS 3	AIS 4	AIS 5	Fatal
Front, Near	Vehicle-to-Pole	-2	9	4	32
Front, Near	Vehicle-to-Vehicle	218	103	21	235
Rear, Near	Vehicle-to-Pole	10	0	0	0
Rear, Near	Vehicle-to-Vehicle	5	3	0	5
Far Side					40
	Total Benefit	231	115	25	311

The results in Tables V-113, 114 and 115 show that the bags would save between 267 and 271 additional lives for occupants in near outboard seating positions, annually.

When both near-side and far-side occupants are considered, the bags would save between 267 (combination with 2 sensors) and 311 (curtain with 4 sensors), annually.

G. Head Injury Risk Distribution: Prasad/Mertz vs. Lognormal

The analysis in this chapter was based on the HIC distribution predicted by the expanded Prasad/Mertz curves. The Prasad/Mertz head injury risk curve has been generally accepted by the automotive industry. In addition, the agency's New Car Assessment Program (NCAP) also uses the Prasad/Mertz head injury risk curve. However, some believe that these curves systemically underestimate the variance. In response to concerns, the agency considered an alternative set of curves, "lognormal curves" which utilized a lognormal distribution. The lognormal curve predicts a more gradual increase in the likelihood of death, when compared to the Prasad/Mertz distribution curves. Thus, the lognormal curves would predict a higher proportion of minor injuries and a corresponding lower proportion of serious and fatal injuries, compared to the Prasad /Mertz based curves. Although the lognormal curve predicts a more gradual increase in risk, the test results showed that both the Prasad/Mertz and the lognormal predict a person would be seriously injured without air bags when the head impacts with a pole at 20 mph. With deployed head air bags, an average HIC of 504 was measured with a 50^{th} male test dummy. To determine how these injury distribution curves influence the estimated benefits, we derived head bags effectiveness rates based on these two injury risk curves, as shown in Table V-116.

Table V-116
Effectiveness: Prasad/Mertz vs. Lognormal
20 mph Pole Impact

HIC		**AIS 3**	**AIS 4**	**AIS 5**	**Fatal**
14,242	Prasad/Mertz:	0%	0%	0%	100%
	Lognormal:	0%	0%	0%	100%
504	Prasad/Mertz:	10.01%	2.62%	0.23%	0.01%
	Lognormal[1]:	3.90%	0.29%	0.31%	0.34%
Effectiveness	Prasad/Mertz:	---	---	---	100%
	Lognormal:	---	---	---	99.66%

1. HIC score of 500 was used.

The effectiveness rates in Table V-116 show that the use of Prasad/Mertz or the lognormal would result in the same effectiveness rate in head-to-pole impacts at a delta-V of 20 mph. For the head-to-vehicle interior impact case, HIC scores of 869 and 316 were calculated at a delta-V of 20 mph, as shown below:

Table V-117
Effectiveness: Prasad/Mertz vs. Lognormal 20 mph Pole Impact

HIC[1]		**AIS 3**	**AIS 4**	**AIS 5**	**Fatal**
869	Prasad/Mertz:	28.20%	9.21%	1.16%	0.05%
	Lognormal:	10.34%	1.44%	1.50%	3.74%
316	Prasad/Mertz:	5.12%	1.31%	0.10%	0.00%
	Lognormal:	1.42%	0.06%	0.06%	0.04%
Effectiveness	Prasad/Mertz:	81.84%	85.78%	91.38%	100.00%
	Lognormal:	86.27%	95.83%	96.00%	98.93%

1. HIC scores of 850 and 350 were used

The results in Table V-117 show that the effectiveness rates are very close, whether the Prasad/Mertz or the lognormal was used.

VI. TECHNICAL COSTS AND LEADTIME

In this chapter, we discuss the cost of the different technologies that could be used to comply with the tests and estimate the compliance test costs. There are a variety of potential ways for manufacturers to meet the test requirements. The agency believes that side air bags for the head and thorax will be used to pass the test and that many manufacturers will have to make their current side air bags wider. The costs for three countermeasure systems are analyzed in this chapter:

1) The combination head/thorax side air bag in the front seat, 2 sensor system
2) The window curtain for the front and rear seat, side thorax air bag for the front seat, 2 sensor system
3) The window curtain for the front and rear seat, side thorax air bag for the front seat, 4 sensor system

Installing a side window curtain air bag on the side roof rail, will cause some models to be redesigned. The normal redesign cycle for passenger car models is 4-5 years, while pickup trucks and some vans have longer redesign cycles of 6-7 years. The costs to design a model to install a window curtain are small if it is done at the time of a normal redesign. NHTSA believes the most cost-effective way to accomplish this redesign task is to allow sufficient leadtime to redesign most vehicles during their normal redesign cycle. Thus, since we are providing sufficient leadtime, we have not added costs for redesigning models.

Other countermeasures the manufacturers could potentially use include improving their vehicle structure for the pole test and including interior vehicle padding for the chest area. We believe, based on the vehicles we tested, that side head and thorax air bags will be sufficient to meet the test for almost all of the vehicles we tested (with the possible exception of a heavy light truck). Costs for structural changes and padding countermeasures are not included in the cost estimates.

A. Current Side Air Bag Technology Costs (in 2004 Dollars)

Several cost estimates come from two NHTSA contractor teardown studies of side air bags[106]. Based on these studies, we estimate the current window curtain head air bag costs $130.87[107] per vehicle (for two). The current thorax air bags are estimated to cost $63.83 per vehicle (for two)[108]. The current combination head/thorax air bags[109] are estimated to cost $75.47 per vehicle (for two). Side impact sensors are estimated to cost $36.67 per vehicle for two (one sensor per side). Some vehicles with window curtains have two sensors and others have four sensors, which we assume will cost twice as much ($73.34). Changes to the frontal electronic control module to add side impact sensor signals and necessary wiring are estimated to cost $3.56. Thus, the total cost to a vehicle for two current separate thorax side air bags and head window curtains is estimated to be $234.93 ($63.83 for the thorax bags, $130.87 for the window curtain

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[106] "Advanced Air Bag Systems Cost, Weight, and Lead Time Analysis," Summary Report, Contract No. DTNH22-96-0-12003.
"Teardown Cost Estimates of Automotive Equipment Manufactured to Comply with Motor Vehicle Standard, FMVSS 214(D) – Side Impact Protection, Side Air Bag Features," AVK Engineering, April 30, 2003.

[107] Taking variable manufacturing costs of $38.22*1.51 to mark it up to consumer costs * 1.1339 to go from 1999 economics to 2004 economics * 2 per vehicle = $130.87. The consumer price index – all urban consumers was used to mark up prices. 2004 = 188.9, 1999 = 166.6, 188.9/166.6 = 1.1339.

[108] This thorax air bag estimate is based on the average cost estimates of the 2001 Chevrolet Suburban ($73.89) and the 2001 Lexus RX 300 ($47.69) in 2002 economics, which were marked up by 188.9/179.9 = 1.05 to 2004 economics.

[109] This combination head/thorax bag estimate is based on the average cost estimates of the 2001 Lincoln Town Car ($85.44) and the 2001 Chrysler Town and Country minivan ($58.32) in 2002 economics, which were marked up by 188.9/179.9 = 1.05 to 2004 economics.

air bag system, $36.67 for the sensors and $3.56 to connect to the already existing electronic control module). The total cost to a vehicle for two current combination head/thorax air bags is $115.70 ($75.47 for the combination head/thorax bags, $36.67 for the sensors and $3.56 to connect to the already existing electronic control module).

1. Size of the Air Bag

The agency believes that an air bag that just meets the optional FMVSS No. 201 perpendicular pole test will have to be widened to meet an oblique pole. Also, the oblique pole test with the 50^{th} percentile male and 5^{th} percentile female test dummies would require wider air bags, including both head and thorax air bags, when compared to current head and thorax air bags designed to comply with the FMVSS No. 201 optional pole test. A wider air bag would require additional air bag fabric and also a larger and more powerful inflator to fill the increased volume. The wider window curtain estimates are based on the teardown study's unit material cost estimates, materials used for the Volvo window curtain as shown in Table VI-1. We estimate that bringing the window curtain closer to the A-pillar will cost $3.15 per vehicle for additional air bag fabric and additional inflator capability.

Table VI-1.
Curtain and Side Air bag System Consumer Costs
(in 2004 dollars)[110]

Air Bag System (two)	**Air Bag Material**	**Inflator**
Volvo Curtain Head Air Bag Assembly	$40.61	$48.73

[110] The basic figures for these estimates come from Figure 2, which are in 1999 economics and are variable costs for one air bag. The costs in this table were increased from 1999 economics to 2004 economics using the Consumer Price Index by a multiplier of 1.1339. The costs were further brought up to consumer costs by inflating variable manufacturer costs by a factor of 1.51 to account for fixed costs, overhead burden, manufacturer profit and dealer profit and multiplying by 2 because there are two bags per vehicle. $11.86*1.51*1.1338*2 = $40.61 and $14.23*1.51*1.1339*2 = $48.73.

A combo air bag deploys in two stages, firstly away from the occupant to protect the chest area, then upward to protect the head and neck, as an air bag shown in its inflated state in Figure 1. The air bag system consists of a side impact sensor and an air bag assembly. The air bag assembly consists of locknuts, an inflator, an air bag casing/frame, a studded flange, an air bag and a cover. Typically, the air bag consists of two chambers: lower and upper chambers, and it is installed in the outer seat back. The air bag assembly is attached to the seat structure with locknuts, and the communication wires from a control module are connected to the air bag assembly. We have cost estimates for two thorax air bags and two combination head/thorax air bags, all of which are different sizes and different costs. Based on these data, a subjective judgment was made of the costs needed to make current air bags wider to pass the oblique impact test. Based on our analysis in Chapter III, we believe that thorax air bags will have to be wider than 12 inches and head air bags wider than 16 inches to meet the oblique impact tests.

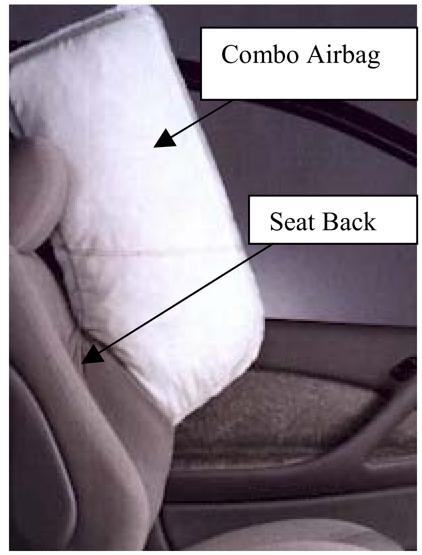

Figure 1. Side Impact "Combo" Airbag

We believe that for a wider air bag, all of the assembly costs would remain the same. The only difference would be in the direct material costs for the air bag and for the inflator. Cost comparisons are made for each component, as follows:

(1) Air bag: since the materials used for air bags are similar in characteristics regardless of air bag types, it would be reasonable to assume that the amount of material used only affects the unit material cost.

(2) Inflator: a typical inflator consists of an electrical initiator unit, a casing and propellants. The electrical initiator unit contains a small electrical wire coated with a heat sensitive explosive chemical. When electrical current is applied through the wire, it heats up the wire and ignites the coated chemical; the heat and the sparkles from the initiator ignite the propellants. Typically, an inflator is designed such that an increase in propellant would not require a larger more powerful initiator. Thus, it is reasonable to assume that the same type of initiator would be used for both "combo" and thorax air bag designs; consequently, the difference in cost between the "combo" air bag initiator and the thorax air bag initiator would be insignificant. As for the casing (that contains the propellants and the electrical initiator), since gases from the inflator need to fill a larger volume within the same "activation time" (i.e., time to fill the air bag), it would require an additional amount of the propellant and a larger casing to house the propellant for a larger combination head/thorax air bag.

The thorax air bags in the cost teardown studies varied in size but were typically 12 inches wide. As discussed in Chapter II, in our oblique pole testing, we have seen the need to make window curtains wider for the oblique test. We have conservatively assumed that thorax air bags and combination air bags may also be made wider to meet the test. We estimate that a slight increase in width will be needed to pass the test and will cost $5.25 per vehicle for thorax bags and we estimate a cost increase of about $10.50 per vehicle for wider combination head/thorax air bags.

2. Electronic Control Module Costs

The electronics of a typical head/side air bag system consists of two, or more, side impact sensors and the central electronic control module including wiring harness. The central electronic control module for frontal air bags is redesigned to process impact signals from both frontal and side impacts.

To separate costs associated with the central electronic module when additional side sensors are added, the air bag electronic cost of BMW 5-series was compared to the electronic cost of BMW Z3. The BMW 5-series occupant protection system consists of frontal and head/side systems; whereas the BMW Z3 is equipped with only a frontal air bag system, as shown in Table VI-2.

Table VI-2
Air Bag Electronic Control Module Costs
Comparing BMW 5-series and BMW Z3
(in 2004 Economics)[111]

Air Bag Electronics	BMW 5-Series Front and Side	BMW Z3 Front Only	Difference in Retail Price
Electronic Control Module	$180.87	$177.31	$3.56

The results in Table VI-2 show that the increase in cost ($3.56) would be rather small (2%) when the central electronic control module of a frontal air bag system is redesigned to process input from sensors in side impact crashes. We assume that this electronics costs is the same for a 2 sensor system or a 4 sensor system per vehicle.

3. Side Impact Sensor Costs

The oblique pole test is aimed at the front seat dummy, so the requirement does not guarantee benefits for the rear seat occupant. The oblique pole test and the MDB test could be sensed by one sensor on the side sill forward of the B-pillar. Most manufacturers with a side air bag

[111] The control module in the BMW 5 was estimated to cost $105.64 variable cost in 1999 economics. The control module for the BMW Z3 was estimated to cost $103.56. Bringing these up to consumer costs and subtracting the difference is $105.64*1.51*1.1339 - $103.56*1.51* 1.1339 = $3.56.

system currently have one side impact sensor near the B-pillar or on the side sill. The oblique pole impact with the 5th percentile female dummy test could push the sensor forward of the B-pillar along the side sill. Some manufacturers with side window curtain air bags have two sensors per side of the vehicle, one on the B-pillar or somewhat forward of the B-pillar on the side sill, and one near the C-pillar. The agency anticipates that the manufacturers will move toward installing side window curtain air bags, which have been designed to physically cover the front and rear window areas. In order to provide appropriate coverage for a rear seat occupant in case of a pole strike near the rear seat, the agency suspects that a second sensor would be needed near the C-pillar area. The agency does not know whether a single sensor can be designed that would pick up vehicle and pole impacts to various parts of the side of the vehicle and deploy the side air bags in impacts at both the front and rear seats. So, for the 4 sensor system, we will be estimating costs to assure that the window curtains deploy to help protect rear seat occupants, and then assessing benefits for the window curtains for rear seat occupants.

One vehicle NHTSA tested deployed the air bags in the oblique pole test with the 5th percentile female dummy (the Saab 9-5). The vehicle has one sensor in the front door on both sides of the vehicle (15" rearward of the front door lip and 17" below the window sill). However, it is doubtful that this system could pick up a pole strike rear of the B-pillar of the vehicle, which is not in our test requirements. The Saab door sensor is pressure-based while the other vehicles tested in the pole test with the 5th percentile female dummy, Ford Explorer and Toyota Camry, have sensors that are acceleration-based. Unlike acceleration-based sensors, a pressure-based sensor is designed to detect door deformation. When a pole strikes rear of the B-pillar of the vehicle, such as the rear door, the impact would not trigger the pressure-based sensor in the front door. A few of the vehicles we tested with side window curtain air bags had four sensors per vehicle (two per side). One sensor was near the B-pillar or a little further forward on the side sill, and one sensor was near the C-pillar.

Based on the contractor's teardown studies, the cost of two side impact sensors varies considerably[112]. Four of the cost estimates were similar between $36.67 and $43.09. The agency assumes that the price of sensor will decline to near the lowest price on the market and assumes that the costs of two sensors will be $36.67. Thus, the agency decided the low end of the range is more likely to occur when a larger number of these sensors are being sold. Some of the current vehicles with side window curtain air bags have two sensors and some have four sensors.

4. Estimated Vehicle Costs for Meeting Oblique Pole Test

Table VI-3 shows our range of cost estimates, although these technologies may or may not actually go into production. For this analysis, the agency will use the teardown cost study estimates where provided. We estimated costs for air bags based on their current width and also based on a wider air bag that might be needed to pass the test. The actual and estimated costs are shown in Table VI-3.

[112] In 2004 economics, the costs for two sensors was $36.67 for the 2001 Chevrolet Suburban, $41.65 for the 2001 BMW 3, $42.74 for the BMW 528i, $43.09 for the 2001 Lincoln Town Car, $73.33 for the 2001 Lexus RX300, and $99.72 for the 2001 Chrysler Town and Country Minivan.

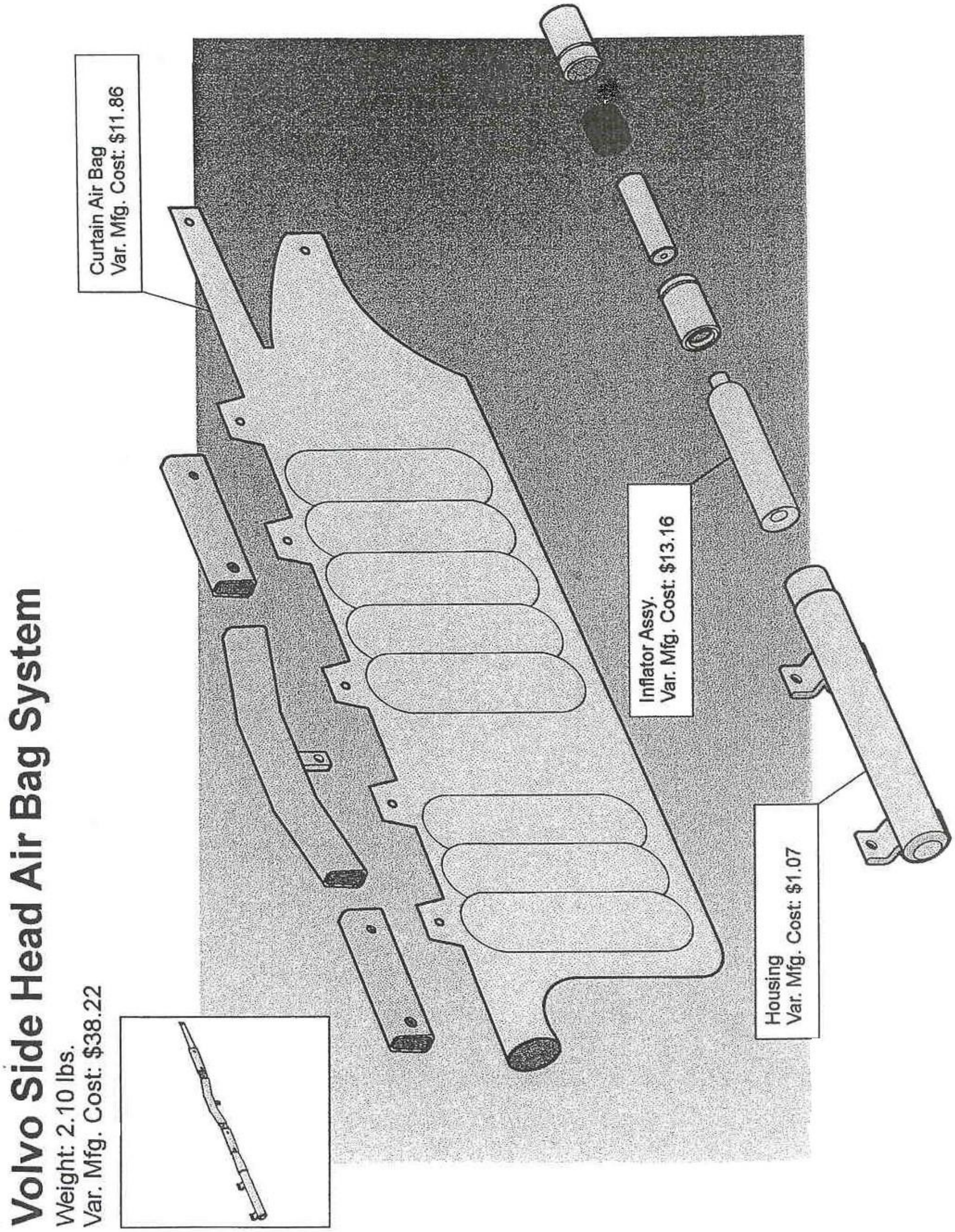

Figure 2. Volvo Side Head Air Bag System

Table VI-3
Technology Cost Summary (in 2004 dollars) Per Vehicle

Air Bag Type	Air Bag	ECM Costs	Sensor Costs (2)	Sensor Costs (4)	Total Cost
Combo (Com)	$75.47				
Wider Combo (W-Com)	$85.97				
Thorax (Th)	$63.83				
Wider Thorax (W-Th)	$69.08				
Curtain (Cu)	$130.87				
Wider Curtain (W-Cu)	$134.02				
System Type					
Combo (Com)	$75.47	$3.56	$36.67		$115.70
Wider Combo (W-Com)	$85.97	$3.56	$36.67		$126.20
Current Curtain Plus Thorax (2 sensor)	$194.70	$3.56	$36.67		$234.93
Wider Curtain Plus Wider Thorax (2 sensor)	$203.10	$3.56	$36.67		$243.33
Current Curtain Plus Thorax (4 sensor)	$194.70	$3.56		$73.34	$271.60
Wider Curtain Plus Wider Thorax (4 sensor)	$203.10	$3.56		$73.34	$280.00

We used the MY 2011projected sales data on specific make/models and how they will be equipped with head and thorax side air bags, from the sales data for those models from the manufacturer's predictions for MY 2011. MY 2011 is used as our baseline to compare incremental costs to current voluntary compliance costs.[113] The combined results of this effort to estimate the percent of sales are shown in Table VI-4. In addition, we used "The Rescuer's Guide to Vehicle Safety Systems, Second Edition, Vehicle Coverage Through 2002", by Holmatro Rescue Equipment, to determine that about 476,300 vehicles have 4 side-impact sensors in their systems currently (about 2.8% of all vehicle sales).

[113] In the benefit chapter, we adjusted the target population to exclude potential ESC benefits in MY 2011 vehicles (by assuming all passenger cars and light trucks would be equipped with ESC). In order to match the baselines (for the target population and costs), we used the MY 2011 sales as our baseline.

Table VI-4
Vehicles Equipped with Head and Thorax Side Air Bags

System	Estimated Percent of MY 2011 Sales
Thorax Only	0.47%
Curtain Plus Thorax	67.38%
Combination	5.28%
Curtain Only	19.19%
ITS Plus Thorax	1.57%
Head Subtotal	93.43%
Thorax Subtotal	74.70%
Any System Subtotal	93.90%

Table VI-4 shows that based on 2011 predicted availability of head and thorax side air bags, an estimated 93.43 percent of the passenger cars and SUV & light trucks are equipped with head air bags, whereas 74.70 percent of the new vehicles are equipped with thorax side air bags.

Table VI-5
Percent Distribution of Head and Side Air Bags

Air Bag Type	Relative Percentage	Air Bag(s) needed
No Air Bag	6.10%	(1) New W-Combo or
		(2) New W-Cu + New W-Th
Curtain + Thorax	67.38%	W-Cu + W-Th
Curtain	19.19%	W-Cu + New W-Th
Combo	5.28%	W-Combo
Thorax	0.47%	(1) New W-Combo or
		(2) New W-Cu + W-Th
ITS + Thorax	1.57%	New W-Th

W = wider, Cu = curtain, Th = thorax air bag, Combo = combination head/thorax side air bag

(1) assumes current vehicles with no air bags would use combination air bag
(2) assumes current vehicles with no air bags would use window curtains and thorax air bags

As shown in Table VI-5 and used throughout the analysis, the agency analyzed two ways that manufacturers that do not supply window curtains or ITS could comply with the proposal (shown as (1) and (2) in the tables). The first way (1) is to use a wider combo bag. The second way (2) is to use wider window curtains and wider thorax bags. While the wider combo bag appears less expensive, there are a few different reasons why the manufacturers might choose the more expensive wider window curtain and wider thorax air bag designs, since the agency has announced its intentions to have an ejection mitigation rulemaking, which may push designs to window curtains.

Compliance Rate of Current Air Bags with the Requirement

The pole test results indicate that many vehicles with current side thorax air bags, combination bags, or window curtains would not meet the oblique pole test requirements. As shown in Table VI-6, when considering that an air bag has to pass both the 50th and 5th percentile dummy tests, we found that for those cases that we had full test data, 4 out of 9 curtains did not meet the final rule test (with the 5th test dummy), the one combination bag did not meet the final rule test, and 4 out of 10 thorax air bags did not meet the final rule test. In some cases the failure was sensor related and in other cases the bag was not wide enough to provide protection. Since sensor costs are handled separately, it is assumed that the bags were not wide enough for those current air bags that did not meet the test.

Table VI-6
Test Results for Current Side Air Bags

Test Vehicle	**Head Bag**	**5th**	**50th**	**Thorax Bag**	**5th**	**50th**
2005 Toyota Corolla	Curtain	P	P	yes	P	**F**
2005 VW Jetta	Curtain	P	P	yes	P	P
2001 Saturn Ion	Curtain	**F**	P	NO	N/A	N/A
2004 Honda Accord	Curtain	P	P	yes	P	P
2005 Beetle Convertible	**Combo**	N/A	P	yes	N/A	P
2005 Saab 9-3 Conv.	**Combo**	N/A	P	Yes	N/A	P
2005 Ford Five-Hundred	Curtain	**F**	P	Yes	**F**	P
2004/05 Toyota Sienna	Curtain	**F**	P	Yes	P	**F**
2005 Subaru Forester	**Combo**	P	**F**	Yes	P	P
2005 Honda CRV	Curtain	P	P	Yes	P	**F**
2005 Chevy Colorado	Curtain	P	P	NO	N/A	N/A
2005 Ford Expedition	Curtain	**F**	P	NO	N/A	N/A
1999 Volvo S80	Curtain	N/A	P	Yes	N/A	**F**
2000 Saab 9-5	**Combo**	N/A	P	Yes	N/A	**F**
2004 Toyota Camry	Curtain	N/A	P	Yes	N/A	P

Total Costs

Table VI-7 shows the incremental costs for manufacturers to meet the requirements compared to the voluntarily supplied side air bags in the MY 2011 fleet, broken down by the types of countermeasure systems currently in use. The results in Tables VI-7 show that the total annual cost for meeting the requirements with a combination head/thorax air bag are estimated to be $429 million. If manufacturers choose to use window curtains and thorax air bags with 2 sensors, the cost are $560 million. If manufacturers choose to use window curtains and thorax air bags with 4 sensors, the costs are estimated to be $1.2 billion annually. The average incremental cost per vehicle with a combination head/thorax air bag is estimated to be $25 per vehicle. If manufacturers choose to use window curtains and thorax air bags with 2 sensors, the average incremental costs are estimated to be $33 per vehicle. If the manufacturers choose to use window curtains and thorax air bags with 4 sensors, the average incremental costs are estimated to be $66 per vehicle.

Table VI-7
Total Incremental Costs and Average Incremental Vehicle Costs*
($2004)

	Combination Head/Thorax Side Air Bags	**Window Curtain and Thorax Side Air Bags 2 Sensors**	**Window Curtain and Thorax Side Air Bags 4 Sensors**
Total Costs	$429 million	$560 million	$1.124 billion
Average Incremental Cost per Vehicle	$25.2	$32.9	$66.1

* See Appendix VI-a for detailed cost calculations

It should be noted that the costs above in Table VI-7 do not assume that the whole fleet is all of one system. For example, for the combination head/thorax air bag system, if a manufacturer already has a window curtain and a thorax bag for a make/model, we do not assume that they will drop their current system in favor of a combination head/thorax air bag. On the contrary, we assume that the window curtain will be made wider and the thorax bag will be made wider to pass the test.

5. Vehicle Modification for Air Bags

Certain types of head air bag systems, such as the ITS and window curtain air bags are installed in the roof rail headliner and anchored to the vehicle structure. The weight and shape of these systems are specifically designed for the roof rail headliner, as shown in Figure 2. The Volvo curtain head air bag weighs only 2.10 lbs. The roof and supporting pillars must already be designed to withstand a force equal to 1.5 times the unloaded vehicle weight, as specified in FMVSS No. 216, Roof Crush Resistance. Thus, if vehicle manufacturers decide to install these systems as a countermeasure, NHTSA believes that the required additional structural material for the roof rail headliner modification on a per-vehicle cost would be insignificant.

Nonetheless, including a window curtain will require a vehicle design modification in the side roof rail area of the inside of the vehicle. For some make/models, the shape of the roof rail area will also need to be changed to accommodate a window curtain. The agency does not have cost estimates for these two cases. However, NHTSA has not included the cost of these structural changes in the estimated cost of the requirements, because of a four-year leadtime, followed by a phase-in schedule for gradually implementing the new requirements. In addition, vehicles with a GVWR greater than 3,855 kg (8,500 lb) are provided until the last year of the phase-in to meet the pole test requirements, since the vehicles have never been regulated under FMVSS No. 214's dynamic requirements and are not subject to the industry's voluntary commitment to install side air bags. The vehicles are provided the substantial lead time to make the structural enhancements needed to meet the pole tests. The cost of making structural modifications to a vehicle is significantly less during a vehicle redesign, compared to the cost of changing an existing model. The leadtime and gradual phase-in of the new requirements would provide manufacturers the opportunity to minimize the costs of the structural changes by incorporating needed changes as part of a vehicle's normal design cycle. (Most passenger cars are redesigned in about a four-year cycle, while most light trucks are redesigned within seven years.) Thus, if manufacturers would implement the vehicle modification (for head and side air bags) as part of the normal manufacturing design cycle, NHTSA believes that there would be little or no modification costs from the requirements.

B. Other Potential Technology Cost

Although the majority of the manufacturers will install air bags to comply with the oblique pole test requirements, other technologies could be used to comply with the requirements, especially for chest, abdomen and pelvis body regions. For example, padding can be used as a standalone system or used with a thorax air bag system. As a standalone system, the agency's test results show that a vehicle equipped with a 3-inch upper thorax pad and 3.5-inch lower pelvic pad reduced TTI(d) score by 25% (from 97 to 72.5) and pelvic g's by 49% (from 177 to 90) at a vehicle delta-V of 26 mph in MDB-to-vehicle tests, without any vehicle structural modification other than the padding. (See "Final Regulatory Impact Analysis, New Requirements for Passenger Cars to Meet a Dynamic Side Impact Test FMVSS 214," pages IIIC-2 and IIIC-10). The MDB test results are shown in Tables VI-8 and 9. The TTI percent reduction result from the padding is comparable to the percent TTI reduction observed in the 18 mph perpendicular pole test with a deployed air bag (14%, from 62.5 to 53.5) but lower than the percent reduction measured in the 20 mph oblique pole test (47%, from 107.0 to 57.0). (Note that the vehicles used in the oblique pole test were not equipped with padding.) In addition, regarding pelvic G's, the test results show that padding is much more effective in reducing pelvic G's when compared to thorax air bags, as shown in Table VI-9.

Table VI-8
Side Impact Occupant Response: MDB Test at 90-degree

NHTSA Test Number	Struck Vehicle	Impact Speed (mph)	Impact Angle (°)	TTI	TTI Effectiveness	Pelvic G's	Pelvic G Effectiveness
512	V. W. Rabbit – unpadded	26	90	97		177	
603	V. W. Rabbit – padded	26	90	72.5	25.3%	90	49.2%
900	V. W. Rabbit – unpadded	22	60	73.0*		93*	
491	V. W. Rabbit – padding	22	60	67.0	8.2%	65	30.1%

* Note that these scores are below the injury criteria.

Table VI-9
Effectiveness of Thorax Air Bag vs. Padding in Reducing Pelvic G's

Impact Speed (mph)	Striking Object	Impact Angle (°)	Countermeasure	Pelvic G Effectiveness
22	MDB	60	Padding	30.1%
20	Pole	75	Thorax Air Bag	-30.8% (increased)
18	Pole	90	Thorax Air Bag	5.4%

If padding reduces the overall TTI level by 25.3%, as observed in the MDB-to-V. W. Rabbit test in Table VI-8, it would reduce the baseline TTI from 107.0 to 82 at a vehicle delta-V of 20 mph in vehicle-to-pole test. If the effectiveness were proportional to the thickness, one and one-half inch padding would reduce the TTI from 107.0 to 93. Based on previous NHTSA work, the estimated cost of padding is $0.05 for one square inch of one inch thick polyurethane padding[114].

[114] See page V-9 of the "Final Economic Assessment, FMVSS 201, Upper Interior Head Protection", June 1995. The consumer cost was estimated to be $0.038 in 1993 economics. This was increased to 2004 economics using the consumer price index (188.9/144.5 = 1.307). Thus, the cost in 2004 economics is $0.038*1.307 = $0.05 per square inch for one inch thick padding. One and one-half inch thick padding was estimated to cost $0.048 per square inch in 1993 economics or $0.063 in 2004 economics ($0.048*1.307).

One and one-half inch padding would cost $0.063 per square inch. If a one-inch thick pad covering a large area of the door were used (for example, 12 inches tall by 16 inches, for a total of 192 square inches), the cost would be $9.60 per door (192*$0.05) or $19.20 for two doors.

Upon review of the comments and the results of our own limited testing with the SID-IIs in the MDB tests, we agree with Nissan and Ferrari that required changes might involve a redesign of the vehicle side structure, particularly to address high pelvic loading and elevated rib deflections of the SID-IIs in the rear seats of some vehicles. This may require a redesign of the arm rest in some vehicles or potentially adding padding for others. We have not added costs into this analysis for these potential impacts since redesigning the arm rests can be done for no or minimal costs and the number of vehicles affected appears to be minimal.

The agency also tested one vehicle over 8,500 lbs. GVWR and found that side structure improvements might be needed for that vehicle to reduce intrusion. It was difficult to determine the countermeasure needs of that vehicle since it did not have a thorax bag, and the agency could not determine whether it could have passed with a thorax bag. It did have more intrusion than most other vehicles and it is possible that some bracing in the side structure might be needed. Since the agency has no way of knowing how many vehicles might be in this situation, or the potential cost of a solution beyond a thorax bag, the agency has not added cost estimates into its analysis for potential structural improvements. However, the agency did consider the potential for structural needs in its leadtime analysis.

B. Compliance Test Costs

This section discusses the estimated costs for the agency to perform compliance tests or potentially for a manufacturer to perform certification tests. Costs are in 2004 dollars.

Currently the agency performs FMVSS No. 214 moving deformable barrier (MDB) tests with 50th percentile male SID dummies. If a manufacturer chooses the FMVSS No. 201 optional pole test, then it is tested with the 50th percentile SID-HIII dummy.

The MDB test with the new dummies will be performed with the 50th percentile male dummy in the front seat and the 5th percentile female dummy in the rear seat. The FMVSS 214 oblique pole test can be performed with the 50th percentile male dummy and the 5th percentile female dummy. The agency will eliminate the FMVSS 201 optional pole test for window curtain air bags. Thus, they will not have to test the same vehicle with two pole tests, perpendicular and oblique. In summary, we will increase the certification requirements of the standards from one required and one optional test to three required tests.

Most of these tests, or tests like these, are already run by the manufacturers and may not be incremental costs for them. The final rule would standardize a minimum set of tests run by the industry on head/side air bags.

The cost of running an MDB test, including the cost of replacing the deformable barrier, averages $21,000 (not including the cost of the vehicle). The cost of running a pole test (either the FMVSS No. 201 optional 90-degree or the 75-degree oblique) is around $16,800. The average cost of a vehicle is $22,000. Thus, the total cost for a MDB test, including the vehicle, is $43,000 and the average cost for running a pole test is $38,800.

Typically, the agency would perform the MDB test and one pole test on a specific make/model. However, manufacturers have to certify to all three test conditions and for both sides of the vehicle. (Usually, the vehicles are symmetrical and the results from one side would be equivalent to the results on the other side.) If a manufacturer ran three tests, the certification costs would be $120,600, compared to the current requirement for one test at $43,000, for an increase of $77,600 per make/model. If a manufacturer chose to run the three tests on both sides of the vehicle (6 tests), the costs would be $241,200, compared to the costs of running the current MDB test on both sides of $86,000, for an increase of $155,200.

The vehicle cost estimates for NHTSA may not reflect the vehicle cost estimates for manufacturers. While the average new vehicle price is around $22,000, manufacturers developing all new models may decide to use a few prototype vehicles for development testing purposes. A prototype vehicle can cost much more than a production vehicle. On the other hand, production vehicle costs to a manufacturer average much less than $22,000 since that price includes manufacturer and dealer profits. The agency believes that most manufacturers are already running perpendicular pole tests and have test facilities available to run these tests. Manufacturers must certify that the vehicles meet the standard but are not required to run the test to prove certification. They can use computer simulations or other means to show that similar platforms will perform well enough to pass the test.

C. Leadtime

In the 214 NPRM, the agency proposed a three-year phase-in of the new test requirements. The proposed phase-in would have begun on September 1, 2011 and by September 1, 2014, all vehicles would have to meet the upgraded pole and barrier test requirements of the standard, as shown below:

<u>Phase-in proposed in the NPRM</u>:

MY 2012: 20%,

MY 2013: 50%,

MY 2014: 100%, except vehicles by alterers, and multi-stage

MY 2015: 100%, including vehicles by alterers, and multi-stage

After reviewing the comments to the NPRM, the results of the 214 fleet testing program and production plans voluntarily submitted by vehicle manufacturers concerning installation of side air bags in vehicles, we have determined that it would be practicable to shorten by two years the 4-year lead time proposed in the NPRM leading up to the beginning of the phase-in pole test requirements. We would thus accelerate the benefits expected to be provided by side air bag systems and other countermeasures by phasing-in the requirements starting with 20 percent of model year (MY) 2010 vehicles. Accordingly, the final rule phase-in schedule, which allows advanced credits, follows:

Table VI-10
Final Rule Phase-In Schedule

Phase-in Date	Percent of each manufacturer's light vehicles
September 1, 2009 to August 31, 2010	20 percent (excluding vehicles GVWR > 8,500 lbs)
September 1, 2010 to August 31, 2011	50 percent vehicles (excluding vehicles GVWR > 8,500 lbs)
September 1, 2011 to August 31, 2012	75 percent vehicles (excluding vehicles GVWR > 8,500 lbs)
September 1, 2012 to August 31, 2013	All vehicles including limited line vehicles, except vehicles with GVWR > 8,500 lbs., alterers, and multi-stage manufacturers
On or after September 1, 2013	All vehicles, including vehicles with GVWR > 8,500 lbs., alterers and multi-stage manufacturers

For the accelerated phase-in schedule, the agency considered several factors that would affect manufacturers' ability to comply with the schedule, including the following:

Side air bag sales: Seven manufacturers, comprising about 90 percent of all light vehicle sales, responded confidentially to a NHTSA request for planned side air bag installations and projected sales through model year (MY) 2011. The sales data were not available when the agency published the notice. The data show that 90 percent of all MY 2010 light vehicles will be equipped with side air bags protecting the head, and 72 percent will be equipped with side air bags protecting the thorax. The percentage of side air bags protecting the head are fairly uniform between the manufacturers, however, there are large differences between manufacturers in the percentage of thorax bags being planned, particularly for light trucks, as shown below:

Side Air Bags Protecting:	MY 2009	MY 2010	MY 2011
Head:	79%	90%	93%
Thorax:	63%	72%	74%

Performance of currently available side air bags: The agency's oblique pole test results show that the majority of currently available head side air bags would meet the requirement (about 80 percent of tested vehicles equipped with head air bags passed the pole test). However, of all the vehicles the agency tested that were equipped with thorax bags, only 56 percent met the chest requirement in the pole test. Our test of one large light truck also failed indicating possibly that structural changes may be needed for large (>8,500 lbs, GVWR) light trucks.

Modifications needed to meet the performance requirements: (a) The pole test data show that side air bags installed in most passenger cars and small & medium size light trucks (including

SUVs and minivans) may not need extensive structural modifications. Some of the window curtains we tested were not wide enough to provide the protection desired in the oblique impacts, particularly when the 5th percentile female dummy was seated full forward in the oblique impact. If a side air bag was minimally designed to meet a perpendicular test, then it would need to be wider to meet an oblique test. We believe that either head or thorax bags could be redesigned and widened with about a two year leadtime. For vehicle models without thorax bags, we estimate that it will take longer than two years to add a thorax bag to a seat. (b) For large light trucks, the test results indicate that structural changes may be needed. This is why we proposed a longer lead time for vehicles with Gross Vehicle Weight Rate greater than 8,500 lbs. Based on our experience, if structural changes are needed, the modification could be done within 3-4 years.

Other considerations: (a) According to the manufacturer's voluntary commitment, all MY 2010 light vehicles will be in compliance with the IIHS MDB test. (b) The agency monitors compliance with the TWG requirements by vehicle manufacturers. We will continue to monitor TWG compliance and will conduct further testing of new air bag designs. However, we do not have any evidence to suggest that the final rule may be in conflict with the TWG procedures. In addition, there have been no fatalities and only one confirmed AIS 3+ injury due to a side air bag, this to a 76-year-old male driver. Side air bags do not appear to pose a safety risk to Out-of-Position (OOP) children, even taking into account exposure risks. (c) NCAP pole testing starting in MY 2009 may compel manufacturers to install more side air bags than what they currently plan to do.

Rationale for expediting and elongating the phase-in schedule: Based on the manufacturer's plans to install head and thorax bags and our belief that side air bag systems could be redesigned to be wider to pass the pole tests in about two years, we have chosen 20 percent with a two-year leadtime so that no manufacturer would be forced to introduce side air bags ahead of their plans. However, those that did not pass the pole test would need to make those bags wider and potentially make other changes to pass the test. The 50 percent with a three-year leadtime theoretically would force one manufacturer to introduce side thorax air bags ahead of their plans (we say theoretically because we don't know if it is possible to pass the pole test without a thorax bag). However, we believe thorax bags could easily be introduced with 3 years of leadtime. The agency decided to elongate the phase-in schedule one year longer than proposed based on the possibility that structural changes might be needed for heavier light trucks and the leadtime necessary to make those changes.

Impact of the expedited phase-in on occupant safety: Comparing the final rule phase-in, that starts earlier, to what we proposed in the NPRM, we expect a total of 545 additional lives would be saved throughout the lifetime of the model years affected during the phase-in period: 62 additional lives for MY 2010 vehicles, 156 additional lives for MY 2011 vehicles, 171 additional lives for MY 2012 vehicles, and 156 additional lives for MY 2013 vehicles.[115]

[115] We estimated that about 311 additional lives would be saved, annually, if the installation increases from the projected 93% to 100% and all vehicles meet the pole requirement in MY 2011. A preliminary analysis shows that the 20% in MY 2010 would result in 62 lives (311 lives x 20% = 62 lives) in MY 2010. In MY 2011, we would claim 50% of the benefits, 156 lives (311 lives x 50% = 156). In MY 2012, the difference between the NPRM phase-in and the new phase-in schedule is 55% (75% - 20% = 55%). The 55% would result in 171 lives (311 x 55% = 177). In MY 2013, the difference between the NPRM phase-in and the new phase-in schedule is about 50% (100% - 50% = 50%). The 50% would result in 156 lives (311 x 50% = 156). Accordingly, the new phase-in would result in a total of 545 additional lives saved.

For the new requirements for the moving deformable barrier (MDB) test, using the ES-2re and the SID-IIs dummies, the effective date will be the same as discussed above for the oblique pole test so that the side of the vehicle can be designed at one time to meet both tests.

APPENDIX VI-a

DETAILED COST CALCULATIONS

TABLE VIa-1
CURTAIN AND THORAX BAG, 2 SENSORS
$ Per Vehicle

		2 Sensors	4 Sensors	Hookup	Curtain	Wide Curt.	Curt. Icre.	Thorax	Wide Thor.	Thor. Incr.	Combo	Wide Comb	Combo Inr.	Total $
		36.67	73.33	3.56	130.87	134.02	3.15	63.83	69.08	5.25	75.48	85.98	10.50	
Current	**Needs**													
No air bag	Wcu, Wth, 2sen, hook	36.67		3.56		134.02			69.08					243.33
Curtain +thorax	C(incr), t(incr)						3.15			5.25				8.40
Curtain	C(incr), Wth.						3.15		69.08					72.23
Combo	Combo(incre)												10.50	10.50
Thorax	Wcu, t(incre),					134.02				5.25				139.27
ITS + Thorax	T(incre)									5.25				5.25

Curtain + Thorax 2 Sensors		**Assuming No Compliance**				**Assuming Compliance As Tested**		
		Total Sales	**Total Cost**			**Total $**	**Total Cost**	
MY 2011		**17000000**	**(Millions)**	**Average**		**Per Vehicle**	**(Millions)**	**Average**
Sales %								
6.10%	No air bag	1,037,264	$252.40	cost		$243.33	$252.40	cost
67.38%	curtain +thorax	11,455,240	$96.22	per		$4.90	$56.13	per
19.19%	curtain	3,263,002	$235.69	Vehicle		$70.48	$229.98	vehicle
5.28%	Combo	897,057	$9.42			$10.50	$9.42	
0.47%	Thorax	79,937	$11.13			$137.52	$10.99	
1.57%	ITS	267,499	$1.40			$3.50	$0.94	
100.00%		17,000,000	$606.26	$35.66			$559.85	$32.93

TABLE VIa-2
COMBINATION HEAD/THORAX 2 SENSORS
$ Per Vehicle

		2 Sensors	4 Sensors	Hookup	Curtain	Wide Curt.	Curt. Icre.	Thorax	Wide Thor.	Thor. Incr.	Combo	Wide Comb	Combo Inr.	Total $
		36.67	73.33	3.56	130.87	134.02	3.15	63.83	69.08	5.25	75.48	85.98	10.50	
Current	**Needs**													
No air bag	WCombo, 2sen, hook	36.67		3.56								85.98		126.20
Curtain +thorax	c(incr), t(incr)						3.15			5.25				8.40
Curtain	c(incr), Wth.						3.15		69.08					72.23
Combo	Combo(incre)												10.50	10.50
Thorax	Wcombo – Thorax												22.14	22.14
ITS + Thorax	t(incre)									5.25				5.25

Combo Bag **2 Sensors**		**Assuming No Compliance**				**Assuming Compliance As Tested**		
		Total Sales	**Total Cost**			**Total $**	**Total Cost**	
MY 2011		**17000000**	**(Millions)**	**Average**		**Per Vehicle**	**(Millions)**	**Average**
Sales %								
6.10%	No air bag	1,037,264	$130.90	cost		$126.20	$130.90	cost
67.38%	curtain +thorax	11,455,240	$96.22	per		$4.90	$56.13	per
19.19%	curtain	3,263,002	$235.69	Vehicle		$70.48	$229.98	vehicle
5.28%	Combo	897,057	$9.42			$10.50	$9.42	
0.47%	Thorax	79,937	$1.77			$22.14	$1.77	
1.57%	ITS	267,499	$1.40			$3.50	$0.94	
100.00%		17,000,000	$475.41	$27.97			$429.13	$25.24

TABLE VIa-3 CURTAIN +THORAX 4 SENSORS $ Per Vehicle														
		2 Sensors	**4 Sensors**	**Hookup**	**Curtain**	**Wide Curt.**	**Curt. Icre.**	**Thorax**	**Wide Thor.**	**Thor. Incr.**	**Combo**	**Wide Comb**	**Combo Inr.**	**Total $**
		36.67	73.33	3.56	130.87	134.02	3.15	63.83	69.08	5.25	75.48	85.98	10.50	
Current	**Needs**													
No air bag	Wcu, Wth, 4sen, hook		73.33	3.56		134.02			69.08					280.00
Curtain +thorax	C(incr), t(incr), 2 sen	36.67					3.15			5.25				45.07
Curtain	C(incr), Wth, 2 sen.	36.67					3.15		69.08					108.90
Combo	Combo(incre)												10.50	10.50
Thorax	Wcu, t(incre),2 sen	36.67				134.02				5.25				175.94
ITS + Thorax	T(incre)									5.25				5.25

Curtain + Thorax 4 Sensors		Assuming No Compliance			**Assuming Compliance As Tested**			
		Total Sales	Total Cost		**Total $**	**Total Cost**		
MY 2011		**17000000**	**(Millions)**	**Average**	**Per Vehicle**	**(Millions)**	**Adjusted for 476,300 Vehicles With 4 sensors**	**Average**
Sales %								
6.10%	No air bag	1,037,264	$290.43		$280.00	$290.43	-$17 mill.	
67.38%	Curtain +Thorax	11,455,240	$516.29	cost	$41.57	$476.19		cost
19.19%	Curtain	3,263,002	$355.34	per	$107.15	$349.63		per
5.28%	Combo	897,057	$9.42	vehicle	$10.50	$9.42		vehicle
0.47%	Thorax	79,937	$14.06		$174.19	$13.92		
1.57%	ITS + Thorax	267,499	$1.40		$5.25	$1.40		
100.00%		17,000,000	$1,186.9 5	$69.82		$1,141.01	$1,124.01	$66.12

TABLE VIa-4
PERPENDICULAR TEST ONLY
CURTAIN +THORAX 2 SENSORS
$ Per Vehicle

		2 Sensors	4 Sensors	Hookup	Curtain	Wide Curt.	Curt. Icre.	Thorax	Wide Thor.	Thor. Incr.	Combo	Wide Comb	Combo Inr.	Total $
		36.67	73.33	3.56	130.87	134.02	3.15	63.83	69.08	5.25	75.48	85.98	10.50	
Current	**Needs**													
No air bag	cu, th, 2sen, hook	36.67		3.56	130.87			63.83						234.93
Curtain +thorax	Nothing													0.00
Curtain	Thorax							63.83						63.83
Combo	Nothing													0.00
Thorax	Cu				130.87									130.87
ITS + Thorax	Nothing													0.00

Curtain + Thorax 2 Sensors		**Assuming No Compliance**				**Assuming Compliance As Tested**		
		Total Sales	**Total Cost**			**Total $**	**Total Cost**	
MY 2011		**17000000**	**(Millions)**	**Average**		**Per Vehicle**	**(Millions)**	**Average**
Sales %								
6.10%	No air bag	1,037,264	$243.68	cost		$234.93	$243.68	cost
67.38%	curtain +thorax	11,455,240	$0.00	per		$0.00	$0.00	per
19.19%	curtain	3,263,002	$208.28	vehicle		$63.83	$208.28	vehicle
5.28%	Combo	897,057	$0.00			$0.00	$0.00	
0.47%	Thorax	79,937	$10.46			$130.87	$10.46	
1.57%	ITS	267,499	$0.00			$0.00	$0.00	
100.00%		17,000,000	$462.42	$27.20			$462.42	$27.20

TABLE VIa-5
PERPENDICULAR TEST ONLY
COMBINATION HEAD/THORAX 2 SENSORS
$ Per Vehicle

		2 Sensors	4 Sensors	Hookup	Curtain	Wide Curt.	Curt. Icre.	Thorax	Wide Thor.	Thor. Incr.	Combo	Wide Comb	Combo Inr.	Total $
		36.67	73.33	3.56	130.87	134.02	3.15	63.83	69.08	5.25	75.48	85.98	10.50	
Current	**Needs**													
No air bag	Combo, 2sen, hook	36.67		3.56							75.48			115.70
Curtain +thorax	Nothing													0.00
Curtain	Thorax							63.83						63.83
Combo	Nothing													0.00
Thorax	Combo – Thorax												11.64	11.64
ITS + Thorax	Nothing													0.00

Combo Bag 2 Sensors		**Assuming No Compliance**				**Assuming Compliance As Tested**		
		Total Sales	**Total Cost**			**Total $**	**Total Cost**	
MY 2011		**17000000**	**(Millions)**	**Average**		**Per Vehicle**	**(Millions)**	**Average**
Sales %								
6.10%	No air bag	1,037,264	(Millions)	Average				cost
67.38%	curtain +thorax	11,455,240	$120.01	cost		$115.70	$120.01	per
19.19%	curtain	3,263,002	$0.00	per		$0.00	$0.00	vehicle
5.28%	Combo	897,057	$208.28	vehicle		$63.83	$208.28	
0.47%	Thorax	79,937	$0.00			$0.00	$0.00	
1.57%	ITS	267,499	$0.93			$11.64	$0.93	
100.00%		17,000,000	$0.00			$0.00	$0.00	
			$329.22	$19.37			$329.22	$19.37

TABLE VIa-6
OBLIQUE TEST ONLY (OVER PERPENDICULAR TEST)
CURTAIN +THORAX 2 SENSORS
$ Per Vehicle

		2 Sensors	4 Sensors	Hookup	Curtain	Wide Curt.	Curt. Icre.	Thorax	Wide Thor.	Thor. Incr.	Combo	Wide Comb	Combo Inr.	Total $
		36.67	73.33	3.56	130.87	134.02	3.15	63.83	69.08	5.25	75.48	85.98	10.50	
Current	**Needs**													
No air bag	c(incr), t(incr)						3.15			5.25				8.40
Curtain +thorax	c(incr), t(incr)						3.15			5.25				8.40
Curtain	c(incr), t(incr)						3.15			5.25				8.40
Combo	Combo(incre)												10.50	10.50
Thorax	c(incr), t(incr)						3.15			5.25				8.40
ITS + Thorax	t(incre)									5.25				5.25

<u>**Curtain + Thorax 2 Sensors**</u>		**Assuming No Compliance**				**Assuming Compliance As Tested**		
		Total Sales	**Total Cost**			**Total $**	**Total Cost**	
MY 2011		**17000000**	**(Millions)**	**Average**		**Per Vehicle**	**(Millions)**	**Average**
Sales %								
6.10%	No air bag	17,000,000	$8.71	cost		$8.40	$8.71	cost
67.38%	curtain +thorax	1,037,264	$96.22	per		$4.90	$56.13	per
19.19%	curtain	11,455,240	$27.41	vehicle		$4.90	$15.99	vehicle
5.28%	Combo	3,263,002	$9.42			$10.50	$9.42	
0.47%	Thorax	897,057	$0.67			$6.65	$0.53	
1.57%	ITS	79,937	$1.40			$3.50	$0.94	
100.00%		267,499	$143.84	$8.46			$91.72	$5.40

TABLE VIa-7
OBLIQUE TEST ONLY (OVER PERPENDICULAR TEST)
COMBINATION HEAD/THORAX 2 SENSORS
$ Per Vehicle

		2 Sensors	4 Sensors	Hookup	Curtain	Wide Curt.	Curt. Icre.	Thorax	Wide Thor.	Thor. Incr.	Combo	Wide Comb	Combo Inr.	Total $
		36.67	73.33	3.56	130.87	134.02	3.15	63.83	69.08	5.25	75.48	85.98	10.50	
Current	**Needs**													
No air bag	Wcu, Wth, 2sen, hook												10.50	10.50
Curtain +thorax	c(incr), t(incr)						3.15			5.25				8.40
Curtain	c(incr), Wth.						3.15			5.25				8.40
Combo	Combo(incre)												10.50	10.50
Thorax	Combo(incre)												10.50	10.50
ITS + Thorax	t(incre)									5.25				5.25

Combo Bag 2 Sensors		**Assuming No Compliance**				**Assuming Compliance As Tested**		
		Total Sales	**Total Cost**			**Total $**	**Total Cost**	
MY 2011		**17000000**	**(Millions)**	**Average**		**Per Vehicle**	**(Millions)**	**Average**
Sales %								
6.10%	No air bag	1,037,264	$10.89	cost		$10.50	$10.89	cost
67.38%	curtain +thorax	11,455,240	$96.22	per		$4.90	$56.13	per
19.19%	curtain	3,263,002	$27.41	vehicle		$4.90	$15.99	vehicle
5.28%	Combo	897,057	$9.42			$10.50	$9.42	
0.47%	Thorax	79,937	$0.84			$10.50	$0.84	
1.57%	ITS	267,499	$1.40			$3.50	$0.94	
100.00%		17,000,000	$146.19	$8.60			$94.21	$5.54

TABLE VIa-8 OBLIQUE TEST ONLY (OVER PERPENDICULAR TEST) CURTAIN +THORAX 4 SENSORS $ Per Vehicle														
		2 Sensors	**4 Sensors**	**Hookup**	**Curtain**	**Wide Curt.**	**Curt. Icre.**	**Thorax**	**Wide Thor.**	**Thor. Incr.**	**Combo**	**Wide Comb**	**Combo Inr.**	**Total $**
		36.67	73.33	3.56	130.87	134.02	3.15	63.83	69.08	5.25	75.48	85.98	10.50	
Current	**Needs**													
No air bag	Wcu, Wth, 2sen, hook	36.67					3.15			5.25				45.07
Curtain +thorax	c(incr), t(incr) 2 sen	36.67					3.15			5.25				45.07
Curtain	c(incr), Wth. 2 sen	36.67					3.15			5.25				45.07
Combo	Combo(incre)												10.50	10.50
Thorax	C(incre), t(incre),2sen.	36.67					3.15			5.25				45.07
ITS + Thorax	t(incre)													0.00

Curtain/ Thorax 4 Sensor		**Total Sales 17000000**	**Total Costs Millions**	**Average**		**Total $ Per Vehicle**	**Total Cost (Millions)**	**Adjusted for 476,300 Vehicles With 4 sensors**	**Average**
MY 2011									
Sales %									
6.10%	No air bag	1,037,264	$46.75			$45.07	$46.75	$17.47 mil	
67.38%	curtain +thorax	11,455,240	$516.29	cost		$41.57	$476.19		cost
19.19%	curtain	3,263,002	$147.06	per		$41.57	$135.64		per
5.28%	Combo	897,057	$9.42	vehicle		$10.50	$9.42		vehicle
0.47%	Thorax	79,937	$3.60			$43.32	$3.46		
1.57%	ITS	267,499	$0.00			$0.00	$0.00		
100.00%		17,000,000	$723.12	$42.54			$671.47	$654	$38.47

VII. COST-EFFECTIVENESS AND BENEFIT-COST ANALYSES

A. Cost –Effectiveness Analysis

The intent of the rulemaking is to minimize deaths and injuries in side crashes. To achieve this goal, NHTSA is requiring a new pole test that is similar to but better than the FMVSS No. 201 optional pole test, to ensure that occupants are provided head and improved whole body protection under non-rollover side crash environments.

The oblique pole test would be conducted with both the 50th male and 5th female dummies. Three countermeasures were examined for costs and benefits. We will show the costs and benefits of the combination head/thorax side air bag, and window curtain thorax air bag countermeasures.

As a primary measure of the impact of the pole test, this analysis will measure the cost per equivalent life saved. In order to calculate a cost per equivalent fatality, nonfatal injuries must be expressed in terms of fatalities. This is done by comparing the value of preventing nonfatal injuries to the value of preventing a fatality. Comprehensive values, which include both economic impacts and lost quality (or value) of life considerations will be used to determine the relative value of fatalities and nonfatal injuries. These values were taken from the most recent study published by NHTSA. In Table VII-1, the process of converting nonfatal injuries to its fatal equivalent is shown. The third column of Table VII-1 shows the comprehensive values used for each injury severity level, as well as the relative incident-based weights for nonfatal injuries, AIS 1-5.

In Chapter V, head and side air bag benefits were derived for the combination head/thorax side air bag countermeasure, as shown in Table VII-1.

Table VII-1
Process of Converting Nonfatal Injuries to Equivalent Fatalities
(Resulted from combination head/thorax side air bag (Combo) countermeasure)

Injury Severity	No. of Fatalities and Injuries	Conversion Factor	Equivalent Fatalities (Undiscounted)
Fatalities	266	1.0	266
AIS 5	25	0.7124	18
AIS 4	112	0.2153	24
AIS 3	215	0.0916	20
Total			328

The results in Table VII-1 show that the combination head/thorax side air bags would save 328 equivalent fatalities.

In Table VII-2, the safety benefits from Table VII-1 have been discounted at a 3% and also 7% rate to express their present value over the lifetime of one model year's production. Although passenger cars and light trucks have different adjustment factors at a given percent discount rate, the average of these adjustment factors was used for the discount based on the assumption that future sales will be approximately 50 percent passenger cars and 50 percent light trucks. The discount factors and the discounted fatal equivalents are summarized in Table VII-2.

Table VII-2
Present Discounted Value of Lives Saved
(Combo bags)

Fatal Equivalent	Discount Rate[116]	Discounted Fatal Equivalent
328	0.8155 at 3%	268
328	0.6489 at 7%	213

[116] The 3% discount factor for passenger cars is 0.8304 and for light trucks is 0.8022. The 7% discount factor for passenger cars is 0.6700 and for light trucks is 0.6303. For additional information, see “Vehicle Survivability and Travel Mileage Schedules,” Lu. S., NHTSA Technical Report, January 2006, DOT 809 952, Docket No. 22223-2218.

The discounted fatal equivalents in Table VII-2 show that combo side air bags would save 268 and 213 equivalent lives when discounted at 3% and 7%, respectively.

The total annual costs from Table VI-6 for vehicles with combination head/thorax side air bags with two sensors per vehicle were divided by the discounted fatal equivalent from Table VII-2 to produce estimates of the cost per equivalent life saved, as shown in Table VII-3.

Table VII-3
Range of Costs per Equivalent Life Saved

	Cost (millions)	Equivalent Lives Saved	Costs Per Equivalent Life Saved
Combination head/thorax side air bags	$429	268 (at 3%)	$1.6 million
		213 (at 7%)	$2.0 million
Curtain and Thorax air bags (2 Sensor)	$560	305 (at 3%)	$1.8 million
		242 (at 7%)	$2.3 million
Curtain and Thorax air bags (4 Sensor)	$1,124	306 (at 3%)	$3.7 million
		243 (at 7%)	$4.6 million

The results in Table VII-3 show that the cost per equivalent life saved for the combination head/thorax side air bag system ranges from $1.6 million to $2.0 million at a 3% and 7% discount rate, respectively.

The results for the window curtain and thorax side air bag systems do not take into account their future life saving potential and future costs. In the future, the agency would like to see window curtains designed to provide ejection reduction potential in rollover crashes. There is tremendous potential for saving lives by reducing ejections in rollovers with window curtains.

This would entail additional costs in the form of window curtains that can maintain pressure for several seconds and rollover sensors. When these costs and benefits are added into the equation, we believe that window curtains will cost much less per equivalent life saved.

B. Benefit-Cost Analysis

Effective January 1, 2004, OMB Circular A-4 requires that analyses performed in support of rules must include both cost effectiveness and benefit-cost analysis. Benefit-cost analysis differs from cost effectiveness analysis in that it requires that benefits be assigned a monetary value, and that this value be compared to the monetary value of costs to derive a net benefit. In valuing reductions in premature fatalities, we used a value of $3.7 million per statistical life (in 2004 economics). The most recent study relating to the cost of crashes published by NHTSA[117], as well as the most current DOT guidance on valuing fatalities[118], indicate a value consistent with $3.7 million. This value represents an updated version of a meta-analysis of studies that were conducted prior to 1993. More recent studies indicate that higher values may be justified.[119]

When accounting for the benefits of safety measures, cost savings not included in value of life measurements must also be accounted for. Value of life measurements inherently include a value for lost quality of life plus a valuation of lost material consumption that is represented by measuring consumers after-tax lost productivity. In addition to these factors, preventing a motor

[117] L. Blincoe, A. Seay, E. Zaloshnja, T. Miller, E. Romano, S. Luchter, R. Spicer, (May 2002) "The Economic Impact of Motor Vehicle Crashes, 2000". Washington D.C.: National Highway Traffic Safety Administration, DOT HS 809 446.

[118] "Revised Departmental Guidance, Treatment of Value of Life and Injuries in Preparing Regulatory Evaluations", Memorandum from Kirk K. Van Tine, General Counsel and Linda Lawson, Acting Deputy Assistant Secretary for Transportation Policy to Assistant Secretaries and Modal Administrators, January 29, 2002.

[119] For example, Miller, T.R. (2000): "Variations Between Countries in Values of Statistical Life", Journal of Transport Economics and Policy, 34, 169-188.

vehicle fatality will reduce costs for medical care, emergency services, insurance administrative costs, workplace costs, and legal costs. If the countermeasure is one that also prevents a crash from occurring, property damage and travel delay would be prevented as well. The sum of both value of life and economic cost impacts is referred to as the comprehensive cost savings from reducing fatalities.

The countermeasures that result from FMVSS No. 214 affect vehicle crashworthiness and would thus not involve property damage or travel delay. The 2002 NHTSA report cited above estimates that the comprehensive cost savings from preventing a fatality for crashworthiness countermeasures was $3,346,967 in 2000 economics. This estimate is adjusted for inflation to the 2004 cost level used in this report. Based on the CPI ALL Items index (188.9/172.2), this would become $3,671,556. The basis for the benefit-cost analyses will thus be $3.7 million.

Total benefits are derived by multiplying the value of life by the equivalent lives saved. The net benefits are derived by subtracting total costs from the total benefits, as shown in Table VII-4.

Table VII-4
Net Benefits with a Value of $3.7M per Equivalent Life

Oblique Pole	Benefits ($M)		Net Benefit ($M)	
	3%	7%	3%	7%
Combo + 2 sensors	$990	$787	$561	$357
Curtain + 2 sensors	$1,127	$895	$567	$336
Curtain + 4 sensors	$1,131	$899	$7	-$225

VIII. Test Data and Analyses of Moving Deformable Barrier

This chapter presents test data available to the agency on the various test procedures specified by the moving deformable barrier test.

The current MDB test specified in FMVSS No. 214 simulates a typical two-vehicle side impact collision and employs a 3,000 lb. moving deformable barrier (MDB) as the striking or "bullet" vehicle. The front structure of the MDB is designed to have the appropriate frontal crush properties of the striking population of vehicles. The MDB consists of a steel structure with a 102 inch wheelbase and a 74 inch track width and a two piece honeycomb block on the front to simulate the energy absorption characteristics of the striking vehicle, as shown in Figure VIII-1.

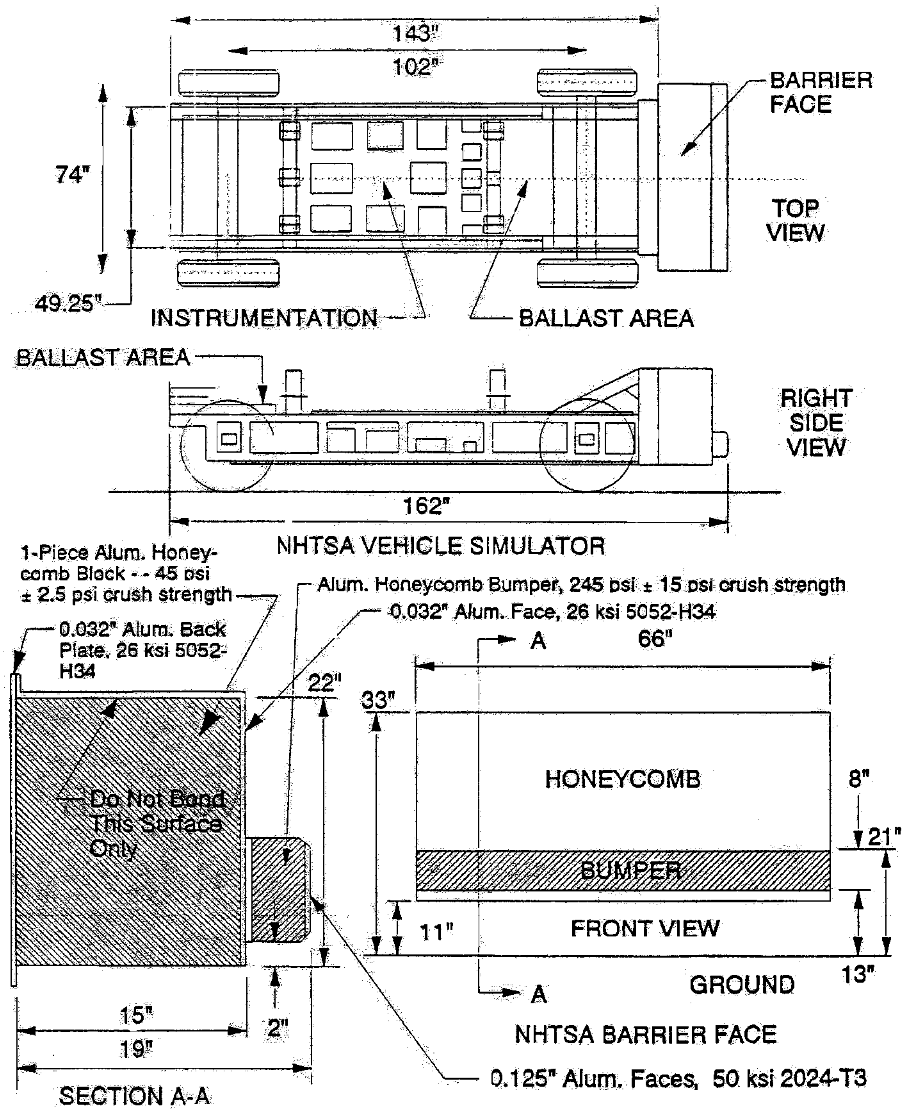

Figure VIII-1. NHTSA Moving Deformable Barrier

FMVSS No. 214 requires 50th percentile male anthropomorphic dummies, the side impact dummy (SID), to measure minimum performance requirements. The dummies are positioned in the front and rear struck side of the vehicle.

1. Replacement of Existing 50th Percentile Male Dummy with ES-2re and Addition of Injury Criteria.

The final rule would require use of an improved 50th percentile male dummy (the ES-2re) in the MDB test in place of SID and would take advantage of the enhanced injury assessment capabilities of the dummy by specifying injury criteria consistent with those developed for the dummy. These criteria are the same ones required by the vehicle-to-pole test. The agency has conducted FMVSS No. 214 crash tests using the ES-2re and MDBs of various configurations and weights moving at various impact speeds. A total of nine FMVSS No. 214 MDB tests were conducted using the test procedures specified in the standard and the ES-2re in the driver and rear passenger seating positions. Test results are tabulated below in Tables VIII-1 thru -8 for tests of the dummy in the driver and rear passenger positions, respectively.

Table VIII-1
FMVSS No. 214 MDB Test Results
Baseline – Without Thorax Bag at Driver Seating Position
(ES-2re Driver)

Test Vehicle	Thorax Bag	Rib-Def. (mm)	Lower Spine (g)	Abd.-Force (N)	Pubic-Symph. (N)
		Req. 44	Req. 82	Req. 2.5k	Req. 6.0k
2001 Ford Focus	None	36	60	1,648	2,833
2002 Impala	None	46	49	1,225	1,789
2001 Saturn Ion	None	29	52	1,524	2,431

Table VIII-2
ES-2re Driver Dummy Baseline Measurements
Average, Maximum and Minimum
MDB

Measurement	Average	Std. Dev.	Max.	min.
Baseline Chest Deflection (mm)	37	8	46	29
Baseline Abdominal Force (N)	1,466	217	1,648	1,225
Baseline Pelvis Force (N)	2,351	527	2,833	1,789

Table VIII-3
FMVSS No. 214 MDB Test Results
With Thorax Bag at Driver Seating Position
(ES-2re Driver)

Test Vehicle	Thorax Bag	Rib-Def. (mm)	Lower Spine (g)	Abd.-Force (N)	Pubic-Symph. (N)
2005 Toyota Corolla	Torso	25	40	722	3,222
2005 VW Jetta	Torso	26	28	733	1,969
2004 Honda Accord	Torso	37	38	557	1,983
2005 Ford Five-Hundred	Torso	25	35	1,006	1,176
2005 Subaru Forester	Combo	21	33	598	1,694
2005 Honda CRV	Torso	35	31	524	1,137

Table VIII-4
ES-2re Driver Dummy Measurements
Average, Maximum and Minimum
MDB

Measurement	Average	Std. Dev.	Max.	min.
Chest Def with Th bag (mm)	28	6	37	21
Chest Def, if failed (mm)	46	N/A	N/A	N/A
Chest Def, if met Req. (mm)	29	6	37	21
Low Spine Accl with Th bag (g)	34	5	40	28
Low Spine Accl, if failed (g)	All passed	N/A	N/A	N/A
Low Spine Accl, if met (g)	41	11	60	28
Abd Force with Th (N)	690	177	1,006	524
Abd Force, if failed (N)	All passed	N/A	N/A	N/A
Add Force, if met (N)	949	426	1,648	524
Pelvis Force with Th bag (N)	1,864	762	3,223	1,137
Pelvis Force, if failed (N)	All passed	N/A	N/A	N/A
Pelvis Force, if met (N)	2,026	701	3,223	1,137

The results in Tables VIII-1 show that the 2001 Ford Focus and 2001 Saturn Ion would comply with the FMVSS No. 214 MDB test requirements when they are tested with the ES-2re dummy and its associated injury criteria. The Ford Focus is a small car and the Saturn is a compact car. Based on our experience in FMVSS No. 214 rulemaking, the small car class is likely to require greater modifications and redesign in order to comply with the standard. The task is easier for large vehicles with a high ride height. The test results of the Ford Focus and Saturn Ion indicate that an upgraded MDB test using the ES-2re dummy and its associated injury criteria would be practicable. An average chest deflection of 37 mm was measured with the baseline vehicles (i.e., without thorax air bags). With thorax air bags, the results show that none of the vehicles equipped with thorax bag failed. An average chest deflection of 28 mm was measured with thorax air bags.

For rear occupant seating positions, none of the vehicles were equipped with thorax air bags.

The results are shown below:

Table VIII-5
FMVSS No. 214 MDB Test Results
ES-2re Rear Passenger

Test Vehicle	Thorax Bag	Rib-Def. (mm)	Lower Spine (g)	Abd.-Force (N)	Pubic-Symph. (N)
2001 Ford Focus	None	20	59	1,121	2,759
2002 Impala	None	12	58	*4,409*	2,784
2005 Toyota Corolla	None	20	58	1,355	2,771
2005 VW Jetta	None	29	53	1,378	2,542
2001 Saturn Ion	None	27	47	1,511	2,275
2004 Honda Accord	None	23	53	810	2,405
2005 Ford Five-Hundred	None	25	44	1,649	1,407
2005 Subaru Forester	None	23	35	967	1,948
2005 Honda CRV	None	5	33	1,192	1,847

The test results also show that the 2002 Chevrolet Impala would not comply with all of the FMVSS No. 214 MDB test requirements because the abdominal force of the rear seat dummy exceeds the 2,500 N limit by a large margin[120]. An examination of the passenger compartment interior reveals that the rear armrest design and location may be the problem. The armrest is made of foam material and its main portion is approximately 75 mm (3 inch) in width, 75 mm (3 inch) in height, and 250 mm (12 inch) in length. The lower edge of the armrest is approximately 100 mm (4 inches) above the seat surface. During a MDB side impact test, the protruded armrest would contact the abdominal area of a 50th percent male dummy that is placed in the rear outboard seating position on the struck side. It seems evident that the armrest of the Chevrolet

[120] Hypothetically, 29% and 96% effectiveness rates would be calculated for AIS 3 and AIS 4+ abdominal injuries, respectively, as shown below:

	Abdominal Force (N)	AIS 3+	AIS 4+	AIS 3
Measured	4,409	96.7%	53.1%	43.6%
Required	2,500	33.0%	1.9%	31.1%
Effectiveness	---	65.9%	96.4%	28.6%

If there were MAIS 4+ abdominal injuries in the rear in vehicle-to-vehicle/other crashes, the effectiveness rate (96.4%) and the passing rate (89%) show that the requirement would prevent about 10% of the abdominal injuries. Although the failed abdominal data show that there is a need for the MDB test, especially for occupants in the rear, we are unable to quantify the benefits because the 2000-2004 data do not show any MAIS abdominal injuries. We suspect that there are some abdominal injuries in vehicle-to-vehicle/others crashes and these injuries would show up if the AIS scale were used, rather than the MAIS scale.

Impala can be modified to alleviate this situation. A common modification is to extend the lower edge of the armrest to completely cover the lower torso of the test dummy. This design has already been used in many vehicles. However, this particular modification may reduce the rear seat width by a small amount.

2. Addition of 5th Percentile Female Dummy (SID-IIs) and Injury Criteria

The final rule upgrades the MDB requirements of FMVSS No. 214 by requiring vehicles to comply when tested with the 5th percentile female dummy (SID-IIs) in the rear passenger seating positions. The agency requires that the criteria for the vehicle-to-pole test must also be met in the MDB test with the SID-IIs.

NHTSA tested eight different vehicles to FMVSS No. 214's MDB test procedure using the SID-IIs in the driver and rear passenger seating positions. Test results[121] are tabulated below in Tables VIII-6 thru –8.

Table VIII-6
FMVSS No. 214 MDB Test Results
Without Thorax Bag at Driver Seating Position, (SID-IIs Driver)

Test Vehicle	Thorax Bag	Rib-Def. (mm)	Lower Spine (g)	Pubic-Symph. (N)
2001 Saturn Ion	None	19	53	8,993

[121] There is no chest deflection limit for the SID-IIs in the final rule. Deflection is being monitored only.

Table VIII-7
FMVSS No. 214 MDB Test Results
With Thorax Bag at Driver Seating Position, (SID-IIs Driver)

Test Vehicle	Thorax Bag	Rib-Def. (mm)	Lower Spine (g)	Pubic-Symph. (N)
2005 Toyota Corolla	Torso	17	59	4,655
2005 VW Jetta	Torso	12	30	2,639
2004 Honda Accord	Torso	20	50	4,150
2005 Ford Five-Hundred	Torso	16	31	2,140
2005 Subaru Forester	Combo	11	37	3,066
2005 Honda CRV	Torso	16	32	1,350
2005 Suzuki Forenza	Combo	27	53	4,948

Table VIII-8
SID IIs Driver Dummy Measurements
Average, Maximum and Minimum
MDB

	Average	Std. Dev.	Max.	min.
Chest Def with Th bag (mm)	17	5	27	11
Chest Def, if failed (mm)	All passed	N/A	N/A	N/A
Chest Def, if met Req. (mm)	N/A	N/A	N/A	N/A
Low Spine Accl with Th bag (g)	42	12	59	30
Low Spine Accl, if failed (g)	All passed	N/A	N/A	N/A
Low Spine Accl, if met (g)	43	12	59	30
Pelvis Force with Th bag (N)	3,278	1,348	4,948	1,350
Pelvis Force, if failed (N)	8,993	N/A	N/A	N/A
Pelvis Force, if met (N)	3,278	1,348	4,948	1,350

In the MDB tests with the SID-IIs, none of the tested vehicles exceeded the chest protection requirements. The vehicles were equipped with thorax air bags in the front seats. The results in Tables VIII-6 and –8 show a chest deflection of 19 mm and a lower spine acceleration of 53 g without a thorax bag. With thorax air bags, an average chest deflection of 17 mm and an average lower spine acceleration of 42 g were measured. The Saturn Ion would not comply with the FMVSS No. 214 MDB test requirements, since the pelvis force of the dummy exceeds the required injury level. As discussed previously, the armrest design may be the problem, and a simple remedy is readily available.

For rear occupant seating positions, none of the vehicles were equipped with thorax air bags. The results are shown below:

Table VIII-9
FMVSS No. 214 MDB Test Results
SID-IIs Rear Passenger

Test Vehicle	Thorax Bag	Rib-Def. (mm)	Lower Spine (g)	Pubic-Symph. (N)
2005 Toyota Corolla	None	35	57	3,182
2005 VW Jetta	None	*49*	52	3,026
2001 Saturn Ion	None	*47*	73	3,964
2004 Honda Accord	None	30	57	*6,917*
2005 Ford Five-Hundred	None	*45*	42	2,925
2005 Subaru Forester	None	24	43	3,572
2005 Honda CRV	None	37	56	3,149
2005 Suzuki Forenza	None	41	73	*6,557*

Table VIII-10
SID-IIs Rear Passenger Dummy Measurements
Average, Maximum and Minimum, MDB

	Average	Std. Dev.	Max.	min.
Chest Deflection (mm)	39	9	49	24
Lower Spine Acceleration (g)	57	12	73	42
Pelvis Force (N), if fail	6,737	N/A	6,917	6,557
Pelvis Force (N), if met	3,303	392	3,964	2,925

Table VIII-9 show that all vehicles tested met the FMVSS No. 214 chest requirement when tested with the SID-IIs. However, three vehicles show high chest deflection levels (shown in table): 2005 VW Jetta, 2001 Saturn Ion and 2005 Ford Five-Hundred. The Jetta and Ion are compact cars and the Ford is a heavy passenger car. On average, a chest deflection of 47 mm was measured with these vehicles. At this 47 mm deflection level, a relatively high risk of chest injury is predicted, as shown below:[122]

Table VIII-11
SID-IIs Rear Passenger Dummy Chest Deflection vs. Injury Risk
Deflection Higher than 44 mm
MDB

Chest Deflection	AIS 3+	AIS 4+
47 mm	80.56%	37.38%

3. 50th vs. 5th Dummy Response

The results in Tables VIII-4 and –9 show that thorax air bags would be effective in reducing chest injuries in vehicle-to-vehicle crashes. On average thorax bags reduced the dummy chest deflection from 37 mm to 28 mm and the lower spine acceleration from 54 g to 34 g when measured with the ES-2re, 50th percentile test dummy. For the SID-IIs dummy, the bags reduced the deflection from 19 mm to 17 mm and the lower spine acceleration from 53 g to 42 g. The lower spine acceleration scores show that the SID-IIs produced higher scores when compared to the ES-2re 50th percentile test dummy. For rear occupants, an average chest deflection of 21 mm was measured with the ES-2re and an average of 39 mm with the SID-IIs. In addition, the rear SID-IIs shows relatively high chest deflection levels. The results suggest that small stature

[122] Injury Criteria for Side Impact Dummies, May 2004, Shashi Kuppa, National Transportation Biomechanics Research center, National Highway Traffic Safety Administration. Not all vehicles tested met the FMVSS No. 214 pelvic force requirement.

occupants would be more vulnerable to serious chest injuries when compared to occupants represented by a 50th percentile male test dummy.

Benefits[123]

Without doubt, the dummies with abdominal measurements provide an opportunity to determine the potential for armrest injuries. According to our 1997-2002 data, abdominal injuries resulted in 146 fatalities and 128 MAIS 3-5 injuries annually in non-rollover side crashes[124]. Based on our knowledge, the contact point for a majority of these fatalities and injuries is the vehicle's protruding armrest. Since the SID dummy does not measure the abdominal force, this potential injury risk would not be detected in the current FMVSS No. 214 MDB test. Use of the ES-2re dummy could result in the use of countermeasures that could reduce serious abdominal injuries in side crashes.

Front Occupants: The MDB test results show that thorax bags are effective in reducing injury risk, whether the occupants are small stature or represented by a 50th percentile male test dummy, as shown below:

Table VIII-12
ES-2 Chest Deflection, Driver

Thorax Bag	Deflection (mm)	AIS 3+	AIS 4+	AIS 3
Without Air Bag	37	42%	16%	26%
With Air Bag	28	32%	11%	21%

Table VIII-13a
SID-IIs Chest Deflection, Driver

Thorax Bag	Chest Deflection	AIS 3+	AIS 4+	AIS 3
Without Air Bag	19	5.20%	0.785%	4.42%
With Air Bag	17	3.88%	0.579%	3.30%

123 For the actual benefit derivation used in the analysis, see Chapter V.
124 For lateral delta-V of 12-25 mph, 2000-2004 CDS, 2004 FARS, 2004 GES. See Chapter V for additional discussion.

Table VIII-13b
SID-IIs, 5th Lower Spine Acceleration

Thorax Bag	Lower Spine Accel (g)	AIS 3+
W/O Air Bag	53	44.07%
With Air Bag	42	38.18%

Rear Occupant: The SID-IIs chest deflection data indicate that small stature occupants in rear seating positions would be vulnerable to serious chest injuries in vehicle-to-vehicle side crashes. However, as a result of the finale rule, we do not anticipate vehicle manufacturers would provide any additional protection for these occupants since none of the vehicles failed the requirements. Nevertheless, if the agency limits thoracic and abdominal rib deflections measured by the SID-IIs in the FMVSS No. 214 MDB, it would prevent approximately 6 MAIS 3+ additional chest injuries in vehicle-to-vehicle side crashes, annually. [125]

[125] Based on the 2000-2004 agency data, 135 serious (MAIS 3+) and fatal chest injuries occur, annually, for all occupants in rear outboard seating positions. All of the 135 MAIS 3+ injuries were from vehicle-to-vehicle/others side crashes (12 –25 mph, near-side, outboard, etc). Since we do not expect vehicle manufacturers to install thorax bags in the rear and the 5th dummy met the lower spine requirement, we didn't quantify the benefits that would result from the MDB and these crash data. However, if deflection were used, the high deflection measurement (i.e., 47 mm) in the MDB test would result in some benefits, as shown below:

	AIS 3	AIS 4	AIS 5	Fatal	Total
5th Chest Injuries, ESC Adjusted (100%)	5	10	14	1	
Effectiveness	12.51%	65.52%	65.52%	65.52%	
Benefits	1	7	9	1	17

The results in the table above show that if 38 mm thorax deflection were used (50% risk of AIS 3+) as a requirement, the MDB test with a 5th in the rear show that 17 AIS 3+ serious and fatal chest injuries would be prevented, annually, for occupants represented by a 5th female test dummy in the rear. With a 63% passing rate, the MDB test would prevent 6 MAIS 3+ serious and fatal injuries, annually.

IX. ALTERNATIVES

There were a number of alternative regulatory approaches the agency considered for this rulemaking. These alternatives include:

1) The 90-degree pole test in FMVSS No. 201.

2a) A perpendicular barrier test with the 5th percentile dummy, using the IIHS bigger barrier, but applying all of the same injury criteria from this final rule;

2b) The test procedures and injury criteria in the voluntary commitment by the Alliance (a perpendicular barrier test with the 5th percentile dummy, using the IIHS bigger barrier with only the HIC15 injury criteria of 700).

3) Applying the final rule oblique pole test to front and rear seats.

Each of these is discussed below.

Alternative 1: The 90-Degree Pole Test In FMVSS No. 201

This is a perpendicular test run with only a 50th percentile male dummy. We attempted to analyze separately the effect of several aspects of the FMVSS No. 201 pole test. For example, we attempted to examine the cost per equivalent life saved of the perpendicular test itself, then the effect of changing the angle of approach from perpendicular to oblique, and finally the effect of adding the 5th female dummy to the test procedure. However, trying to determine the benefits of these separate aspects and how the manufacturers might react to them individually was difficult, since the benefits cannot easily be finely broken into these categories[126].

[126] In the benefit chapter, we estimate the FMVSS No. 214-bags would save 311 additional lives, annually, with the curtain & 4-sensor system. Among the 311 lives saved, 271 would be from occupants in near side seating positions and 40 would be from far-side seating positions. The benefit analysis shows that for occupants in front outboard seating positions, about 75% of lives saved by the bags are occupants represented by a 50th test dummy (203) and the remaining 25% are occupants represented by a 5th female test dummy (68). When these percentages are applied to the far side additional lives saved (40), it shows that 30 far side occupants represented by the 50th and 10 far side

To illustrate, one way of estimating the incremental benefits of an air bag produced to meet an oblique pole test over that produced to meet a perpendicular test is to analyze crash data to determine how many crashes occur obliquely versus perpendicularly. The crash data provide crashes by clock position. So, we assumed that 3 and 9 o'clock represent the perpendicular crashes and that the oblique test, with the 5th percentile female positioned full forward, would provide benefits at 2, 3, 9, and 10 o'clock. For the combination head/thorax air bag, we did not find any thorax bags or combination bags that did not meet the criteria because they weren't wide enough. However, we only tested 3 combination air bags and if a side air bag was minimally designed to meet a perpendicular test, then it would need to be wider to meet an oblique test. In this analysis, we assume that wider combination air bags will be needed to provide protection in the test conditions. Thus, we could estimate from the crash data the incremental benefits of a combination head/thorax air bag produced to meet an oblique pole test over one made to meet a perpendicular test. However, window curtains produced to date have been wider than what would be needed for just a perpendicular test. Thus, we have had to estimate the coverage provided by window curtains and have assumed that if there were just a perpendicular test that they would cover about 70 percent of the benefit,[127] compared to their benefit with an oblique test requirement.

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occupants represented by the 5th would be saved (40 x 75% = 30, 40 x 25% = 10). Therefore, the FMVSS No. 214-bags would save 233 occupants represented by the 50th male dummy and 78 occupants represented by the 5th.

[127] The percentage is based on the 80% compliance (i.e., passing) rate of the current head air bags tested with the ES-2re, a 50th percentile test dummy. In addition, when all body regions are considered, the 50th has 82% passing rate whereas the 5th has 48% passing rate. It shows that the 5th passing rate is about 60% of the 50th. (48%/82% = 60%). Thus, we assumed that <u>current</u> curtain air bags would be 60% effective for occupants represented by a 5th percentile test dummy when compared to 50th occupants. Thus, Percentage = (passing rate, min.) x [(100% of occupant represented by 50th dummy) + (60% of occupants represented by 5th dummy)]. (80%)x[75% + (0.6)(25%)] = 72%.

In the main analysis we had three compliance scenarios, which a manufacturer might choose to use: (a) a combination head/thorax air bag; (b) a window curtain and thorax air bag with 2 sensors (per vehicle); or (c) a window curtain and thorax air bag with 4 sensors (per vehicle). For a perpendicular test, any of these countermeasures would be very effective; i.e., the combination head/thorax air bag would meet the standard. Thus, there appears to be no reason why a manufacturer would have to use a 4-sensor design if a perpendicular test were adopted, nor a curtain design. (We believe that some manufacturers will elect to install a curtain rather than a seat-mounted combination air bag system, because fewer challenges might be required of present curtain systems than present combination bags to meet the oblique test requirements.) Further, current designs of combination head/thorax air bags are seat-mounted, so "travel" with the seat when the seat is positioned mid-track (when testing with the 50th percentile male dummy or full frontal (when testing with the 5th percentile female dummy). Thus, a combination air bag system meeting a perpendicular test would not have to be wider than present combination air bag systems, even when two crash dummies are used to test the vehicle. As noted earlier, the present combination head/thorax air bags do not necessarily provide protection in the 2 and 10 o'clock crashes.

In contrast, combination seat-mounted head/thorax air bags produced to meet an oblique pole test would have to be wider to provide head coverage in the more forward crash. Similarly, window curtains would have to be wider because of an oblique test, to protect against the 2 and 10 o'clock crashes. Thus, we believe that the oblique test, with the 5th percentile female positioned full forward, would require the manufacturers to use wider, more protective side air bag systems. The benefits would therefore be greater with an oblique angle test over a perpendicular one.[128]

Benefits:

Table IX-1
Incremental Estimated Benefits by Test Feature[†]

	Combination Air Bag 2 Sensors	Curtain & Thorax Bags 2 Sensors	Curtain & Thorax Bags 4 Sensors
Perpendicular Angle	105 fatalities[1]	224 fatalities[2]	224 fatalities[2]
Oblique Angle (wider air bags + possibly more sensors)	162 fatalities	87 fatalities	87 fatalities
Total Benefits for the Proposal	266 fatalities	311 fatalities	311 fatalities
Perpendicular Angle	139 AIS 3-5 Inj.	260 AIS 3-5 Inj.	267 AIS 3-5 Inj.
Oblique Angle (wider air bags + possibly more sensors)	214 AIS 3-5 Inj.	101 AIS 3-5 Inj.	104 AIS 3-5 Inj.
Total Benefits for the Proposal	352 AIS 3-5 Inj.	361 AIS 3-5 Inj.	371 AIS 3-5 Inj.

1. According to the 2000-2004 crash data, 39% of the crashes considered in the analysis were from 3 and 9 o'clock directions and the remaining 61% were from 2 and 10 o'clock directions.
2. 72% of the total oblique benefits.

† The numbers were rounded to the nearest integer.

Costs:

For the perpendicular pole test alternative with the combination air bag, we assume that the combo air bag would be used by those manufacturers with no current air bag systems, or those with only a thorax air bag system. We assumed that those current systems with a window curtain or ITS would keep those systems. We assumed no wider air bags and no additional sensors would be needed.

[128] We note, however, that the information available does not allow a real apples-to-apples comparison of the perpendicular test to the oblique test for two reasons. First, the current side air bags are a variety of sizes and shapes and their benefits could go beyond just a perpendicular crash. Second, we can't parse out the benefits into very discrete angles to determine more closely the potential benefits of different sizes of air bags. That is, we have crash data for crashes recorded as 2, 3, 9 and 10 o'clock crashes, but we do not know how effective a particular size of air bag would be in a crash occurring, e.g., between 2 and 3 o'clock. This analysis points out that the benefits are significant for increasing the angles covered by air bags and the costs are not that significant for widening the air bags.

For the perpendicular pole test alternative with the window curtain and thorax bag, we assume that the window curtain and thorax side air bag would be used by those manufacturers with no current air bag systems, or those with only a thorax air bag system. We assumed that those current systems with an ITS or combination air bag would keep those systems. We assume no wider air bags and no additional sensors would be needed.

Table IX-2
Incremental Estimated Costs by Test Feature

	Combination Air Bag 2 Sensors	Curtain & Thorax Bags 2 Sensors	Curtain & Thorax Bags 4 Sensors
Perpendicular Angle	$329 Million	$462 Million	$470 Million
Oblique Angle (wider air bags + possibly more sensors)	$94 Million	$92 Million	$654 Million
Total Costs	$429 Million	$560 Million	$1,124 Million

Fatality benefits were segregated in the same manner using the estimates above.

Table IX-3 summarizes the cost per equivalent life saved, after discounting benefits by 3 percent and by 7 percent.

Table IX-3
Cost Per Equivalent Life Saved by Test Feature

	Combination Air Bag 2 Sensors	Curtain & Thorax Bags 2 Sensors	Curtain & Thorax Bags 4 Sensors
Perpendicular Angle			
3 % discount rate	$3.13 Million	$2.11 Million	$2.13 Million
7% discount rate	$3.93 Million	$2.65 Million	$2.68 Million
Oblique Angle (wider air bags + possibly more sensors)			
3 % discount rate	$0.58 Million	$1.08 Million	$7.64 Million
7% discount rate	$0.73 Million	$1.35 Million	$9.60 Million
Total Costs per Equivalent Life Saved for the Proposal			
3 % discount rate	$1.60 Million	$1.84 Million	$3.68 Million
7% discount rate	$2.02 Million	$2.31 Million	$4.62 Million

Alternative 2a: The IIHS Taller MDB test

The agency also considered the merits of the Insurance Institute for Highway Safety (IIHS) test procedure. The IIHS test is a perpendicular (90 degree) moving deformable barrier (MDB) test at 50 km/h (30 mph). The MDB is taller (12 inches taller) than NHTSA's MDB and weighs 1,500 kg (3,300 pounds), which is 300 pounds heavier. The agency would apply all of the injury criteria from the final rule in this barrier test.

As of December 2003, IIHS has tested 12 small SUV's and no larger light trucks. Of the 12 small SUV's, nine had no head air bag. Of these nine, five had head strikes to the barrier and four did not. None of the small SUV's with a head air bag had a head strike.

Here are some examples of the tests of small SUVs with no side air bag head protection:

- '03-'06 Honda Element: rated medium (M) for head protection, driver head hit the window sill; HIC15 was 477.
- '02-'06 Saturn Vue: rated poor (P) for head, driver head hit barrier; HIC15 was 553.
- '01-'05 Toyota Rav 4: rated P, driver head hit barrier; HIC15 was 338.
- '01-'06 Escape; rated P, driver head hit barrier; HIC15 was 733.
- '03-06 Mitsubishi Highlander; rated P, driver head hit the barrier; HIC15 was 972.

The differences between the final rule and Alternative 2a can significantly affect the installation of side impact air bags in the fleet. Based on these IIHS tests, the agency estimates that in many of the taller light trucks, the dummy head would not strike the barrier and the HIC would be low, or it may strike the barrier with a low HIC. The agency estimates that about 20 percent of the light truck fleet and all of the passenger car fleet would need head and thorax air bags to pass the IIHS barrier test, and without the oblique angle in the pole test, these air bags would not need to be as wide as required by the oblique test. We assume that the remaining 80 percent of the light truck fleet will need thorax air bags for chest protection in the test. As a result, curtain bags designed for the IIHS MDB test would not be wide enough to protect small stature occupants in oblique impacts. In the pole test the head will be struck unless there is a countermeasure.

If head impact protection were not included for the taller light trucks, because theoretically they could pass the IIHS test without protecting the head, the FMVSS No. 201 pole test benefits would probably be reduced by about 43 percent. (Total benefits are estimated to be about 80 percent from passenger cars and small light trucks and 20 percent from taller light trucks.) Curtain bags that are meeting the requirements in the IIHS MDB would not be wide enough to cover the head of a small stature occupant in oblique impacts, as small occupants would sit close to the steering wheel when compared to larger size occupants.

Alternative 2b: The Voluntary Commitment

The vehicle manufacturers belonging to the Alliance and others have announced that they will begin voluntarily meeting performance criteria for head protection in side impacts when tested to the IIHS test procedure. In the industry's voluntary commitment, a 5th percentile SID-IIs dummy is placed in the driver's seating position. The head injury criterion is 700 for HIC15.

The differences between the voluntary industry commitment and NHTSA using the IIHS barrier are in the chest and pelvic areas. The voluntary commitment does not address these areas. We assume that head air bags would be required for passenger cars and small light trucks (we assume 20 percent of all light trucks), but thorax bags would not be required.[129]

[129] According to the voluntary commitment, 100% of vehicles will meet the head injury recommended threshold value (of $HIC_{15} < 779$, with SID-IIs in Phase 2) by September 2009. In theory, therefore, passenger cars and small LTVs need not be equipped with thorax bags to meet the voluntary occupant protection requirement, only head bags. We estimated that 58% of vehicles are either passenger cars or small LTVs. In addition, we assumed that large LTVs need not be equipped with head bags to meet the voluntary occupant protection requirement due to their

The industry commitment uses a 5th percentile female dummy in the driver's position in a 90-degree MDB test while the final rule uses the 5th percentile female and 50th percentile male dummy in both the driver and right outboard passenger position in a 75-degree pole test. The industry commitment limits HIC, while this rule limits HIC and forces to the chest and pelvic regions. The industry commitment applies to passenger cars and to LTVs with a GVWR of up to 8,500 lbs., while the rule applies the pole test to passenger cars and to LTVs with a GVWR of up to 10,000 lbs.

Alternative 3: Pole Test for Both the Front and Rear Seat

We examined the costs and benefits of having a pole test for the rear seat also. Covering the rear seat will result in costs to provide chest protection for the rear seat occupant. The combination air bag system assumes that a combination air bag will be used for the rear seat. The curtain and thorax air bags assume that a thorax air bag will be used for the rear seat. When the 4 sensor curtain and thorax air bag system is used, we assume the costs of the sensor apply to the rear seat in this analysis. It is estimated that about 80 percent of the light passenger vehicle fleet (passenger cars, pickups, vans, and sport utility vehicles) have a rear seat.

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relatively high seating height with respect to the top of the barrier. In the benefits chapter, we estimated that curtain bags with 2-sensors would prevent 185 fatal head injuries, annually. When the 5th occupants are excluded, the system would save 159 lives. (56% are from 2 & 10 o'clock PDOF oblique impacts and 25% of injured occupants would be small stature occupants: 185 x (1-.56x.25) = 159. In other words, we assumed that the voluntary system would not protect small occupants in oblique side impacts.) Among the 159 lives saved, 92 would be from passenger cars and small LTVs, and the remaining would be from large LTVs. However, as discussed above, the 92 fatal potential benefits would not be realized since LTVs would not be equipped with head bags (when they are designed to meet the IIHS MDB test requirement. Accordingly, 92 lives would be saved by eliminating fatal head injuries when vehicles are designed to meet the IIHS MDB requirement. Of the 92 lives saved, 15 would be from the front vehicle-to-pole/tree, 57 would be from the front vehicle-to-vehicle, and 20 would be from the far-side benefits.

Table IX-4
Incremental Costs and Benefits for a Rear Seat Test

Front Air Bag System	Combination Air Bag with 2 Sensors	Curtain & Thorax Bags with 2 Sensors
Rear Air Bag System	Combination Air Bag with 2 Sensors	Thorax Bag with 2 Sensors
Costs[130]	$1,583 Million	$1,410 Million
Benefits[131]: Fatalities	22	1
Benefits[132]: AIS 3-5	96	29
Equivalent Fatalities, undiscounted	42 (42.35)	14 (13.53)
Cost per Equivalent Fatality		
3% Discount Rate	$45.83 Million[1]	$127.80 Million
7% Discount Rate	$57.60 Million	$160.61 Million

1. $1,583/(42.35 x 0.8155) = $45.83 M/Equ. life

As Table IX-4 shows, the thorax air bags or combination air bags for the rear seat are not cost effective.

After considering the foregoing, the agency decided not to require that the pole test apply to the rear seat. First, thorax air bags in the rear seat are not cost effective. Further, years of conducting the optional pole test in FMVSS No. 201 have yielded substantial information about

130 Costs are for the rear air bag system only for combination bag or thorax bag and an additional 2 sensors for the rear seat. These are incremental costs over the estimated 100,000 vehicles in the MY 2005 fleet that already have rear thorax bags and 476,300 vehicles that already have with 4 sensors.

131 These are additional benefits that were not covered by the front air bag system. As discussed in Chapter V, curtain bags would provide head protection not only for occupants in front seating positions but also occupants in the rear seat, since the bag would cover between the A- and C-pillars. However, combination bags installed in the front would not provide any protection for occupants in the rear. The 22 fatalities saved (as shown in the table) from combination air bags installed in the rear seat mostly result from head protection (21 from head and 1 from chest injuries).

132 Combination air bags in rear seating positions would be effective in reducing head and chest injuries. A total of 21 lives would be saved if combination bags are as effective as the 214-curtain bags in preventing fatal head injuries: 2 lives from vehicle-to-pole/tree and 19 lives from vehicle-to-vehicle side crashes. According to the 2000-2004 crash data, a total of 5 occupants in rear outboard seating positions were killed from chest injuries (12-25 mph, from the vehicle-to-vehicle, see the target population section for additional information). We do not know how effective the hypothetical rear thorax bags are. The crash data show that front thorax bags would save 192 lives out of 779 chest fatal injuries in the front (46 from the vehicle-to-pole/tree and 733 from vehicle-to-vehicle/others, 46+733 = 779). If we use this ratio, the rear thorax bag would save about 1 fatality (5 x 192/779 = 1). For the serious injuries, the rear combo bags would prevent 67 AIS 3-5 head injuries (56 AIS-3 and 11 AIS-4 head injuries) and 29 AIS 3-5 chest injuries), as shown below:

Body Region	AIS 3	AIS 4	AIS 5	Fatal	Equivalent Life
Head	56	11	0	21	28.82
Chest	5	10	14	1	13.53
Total					42.35

meeting pole test requirements in that seat. Less information is known about the rear seat. Also, NHTSA tentatively believes that those air curtains will be large enough to cover both front and rear side window openings.

Summary of Alternatives:

There were a number of alternative regulatory approaches the agency considered for this rulemaking. These alternatives include:

1) The 90-degree pole test in FMVSS No. 201.

2a) A perpendicular barrier test with the 5th percentile dummy, using the IIHS bigger barrier, but applying all of the same injury criteria from this final rule;

2b) The test procedures and injury criteria in the voluntary commitment by the Alliance (a perpendicular barrier test with the 5th percentile dummy, using the IIHS bigger barrier with only the HIC 700 over 15 ms injury criteria).

3) Applying the final rule oblique pole test to front and rear seats.

We compared the incremental costs and benefits associated with these alternatives under the assumption that manufacturers would use the window curtain and thorax bag with 2 sensors as a countermeasure. The costs and benefits are summarized in Table IX-5.

Table IX-5
Incremental Costs and Benefits for Alternatives
(Curtain and thorax system with 2 sensors)

Alternatives	Benefits		Costs (millions)	Cost/Eqv. Life Saved (at 7% discount)
	MAIS 3+	Fatality		
Final Rule (Curtain + 2 sensors)	361	311	$560	$2.3
90-degree pole	260	224	$462	$2.7
IIHS MDB	240	189	$425	$2.9
Voluntary commitment	46	92	$186	$2.7
Front and rear seats[133]	390	312	$1,872	$7.5[134]
(Rear seats, separate)	29	1	$1,410	$160.6

[133] Curtain + front thorax bag (with 2 sensors)+ rear thorax bag, additional benefits:

	AIS 3	AIS 4	AIS 5	Fatal	Total
Curtain + Front thorax bag	221	115	25	311	
Rear thorax bag	5	10	14	1	
Total	226	125	39	312	
Equivalent Factor	0.0916	0.2153	0.7124	1	
Equivalent Lives	20.70	26.91	27.78	312	387.4

[134] When 387.4 equivalent lives saved are discounted at 7%: 387.4 x 0.6489 =251.4. $1,872/251.4 = $7.45. $462 + $1,410 = $1,872

X. REGULATORY FLEXIBILITY ACT AND UNFUNDED MANDATES REFORM ACT ANALYSIS

A. REGULATORY FLEXIBILITY ACT

In compliance with the Regulatory Flexibility Act, 5 U.S.C. 60l et seq., NHTSA has evaluated the effects of the final rule on small entities. The head of the agency has certified that the final rule will not have a significant impact on a substantial number of small entities.

The factual basis for the certification (5 U.S.C. 605(b)) is set forth below. Although the agency is not required to issue a final regulatory flexibility analysis (id. at §605(b)), as a means of venting the issues we discuss below many of the issues that a final regulatory flexibility analysis would address (§604).

- **Overview of the objectives of and legal basis for the final rule**

To vastly improve the safety of occupants in side impacts, this final rule incorporates a dynamic pole test into Federal Motor Vehicle Safety Standard (FMVSS) No. 214, "Side impact protection." To meet the test, vehicle manufacturers will need to assure head and improved chest protection in side crashes. It will lead to the installation of new technologies, such as side curtain air bags and torso side air bags, which are capable of improving head and thorax protection to occupants of vehicles that crash into poles and trees and vehicles that are laterally struck by a higher-riding light truck or van (LTV), or sport utility vehicle (SUV). The side air bag systems installed to meet the requirements of this final rule will also reduce fatalities and injuries caused by partial ejections through side windows.

Vehicles will be tested with two new, scientifically advanced test dummies representing a wide range of occupants, from mid-size males to small females. A test dummy known as the ES-2re will represent mid-size adult occupants. A test dummy known as the SID-IIs will represent small stature occupants. The SID-IIs is the size of a 5th percentile adult female; these adults are about the height of a 12-year-old.

The pole test exposes vehicles to conditions representing a severe crash environment and requires that technologies for head, thorax and abdomen protection be installed in vehicles. The rule ensures not only the installation of air bag-related technologies generally, but ensures that these technologies are effective in protecting consumers ranging from the 5^{th} percentile adult female to 50^{th} percentile adult males.

This final rule also enhances FMVSS No. 214's moving deformable barrier (MDB) test. The current 50th percentile male dummy in the front seat of tested vehicles will be replaced with the more biofidelic ES-2re. In the rear seat, the new 5th percentile female SID-IIs dummy will be used, thus improving protection to a greater segment of occupants seated in rear seating positions.

NHTSA is issuing the final rule under the authority of 49 U.S.C. 322, 30111, 30115, 30117, and 30666; delegation of authority at 49 CFR 1.50. The agency is authorized to issue Federal motor vehicle safety standards that meet the need for motor vehicle safety.

This final rule is also being issued pursuant to the "Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users." Section 10302 of the Act directed the agency "to complete a rulemaking proceeding under chapter 301 of title 49, United States Code, to establish a standard designed to enhance passenger motor vehicle occupant protection, in all seating positions, in side impact crashes." In accordance with §10302, the side impact air bags installed in front seats and vehicle changes made to rear seats will enhance passenger motor vehicle occupant protection in side impacts.

- **<u>Description and estimate of the number of small entities to which the final rule will apply; compliance impacts</u>**

The final rule will affect motor vehicle manufacturers, final-stage manufacturers and alterers, dummy manufacturers, air bag manufacturers, air bag sensor manufacturers, and manufacturers of seating systems. We believe that there will be no significant economic impact on a substantial number of small entities. The impacts on those entities, and on aftermarket businesses, are discussed below.

Business entities are defined as small businesses using the North American Industry Classification System (NAICS) code, for the purpose of receiving Small Business Administration assistance. One of the criteria for determining size, as stated in 13 CFR 121.201, is the number of employees in the firm. For establishments primarily engaged in manufacturing or assembling automobiles, light and heavy duty trucks, buses, motor homes, new tires, or motor vehicle body manufacturing, the firm must have less than 1,000 employees to be classified as a small business. For supplier establishments manufacturing many of the safety systems, the firm must have less than 750 employees to be classified as a small business. For establishments manufacturing motor vehicle seating and interior trim packages, alterers and final-stage manufacturers, the firm must have less than 500 employees to be classified as a small business.

<u>Small vehicle manufacturers</u>

The rule will directly affect motor vehicle manufacturers. The majority of motor vehicle manufacturers do not qualify as small businesses. However, there are four small vehicle manufacturers.

NHTSA requested comments on an addendum to the initial regulatory flexibility analysis (IRFA) that was contained in the Preliminary Economic Assessment (PEA) for the May 17, 2004

NPRM on FMVSS No. 214 (Docket No. 17694). The addendum to the IRFA discusses the economic impacts on the small vehicle manufacturers (70 FR 2105; January 12, 2005).

NHTSA stated in the addendum that our tentative conclusion was that the rule would not have a significant economic impact on the four manufacturers. We believed that the small vehicle manufacturers are not likely to certify compliance with a vehicle test, but will use a combination of component testing by air bag suppliers and engineering judgment. Already much of the air bag work for these small vehicle manufacturers is done by air bag suppliers. Typically, air bag suppliers are supplying larger vehicle manufacturers during the development and phase-in period, and do not have the design capabilities to handle all of the smaller manufacturers. The rulemaking proposal accounted for this limitation by proposing to allow small manufacturers that have limited lines to comply with the upgraded requirements at the end of the phase-in period, to reduce the economic impact of the rule on these small entities.

As explained in the addendum, we also believed that the rulemaking would not have a significant impact on the small vehicle manufacturers because the market for the vehicles produced by these entities is highly inelastic. Purchasers of these vehicles are attracted by the desire to have an unusual vehicle. Further, all light vehicles must comply with the upgraded side impact requirements. Since the price of complying with the rule will likely be passed on to the final consumer, the price of competitor’s models will increase by similar amounts. In addition, we did not believe that raising the price of a vehicle to include the value of a combination head-thorax side air bag will have much, if any, effect on vehicle sales.

The agency received no comments on the addendum to the IRFA concerning the impacts of the rule on small vehicle manufacturers.

For the reasons explained in the IRFA, NHTSA concludes that this final rule will not have a significant impact on small vehicle manufacturers. Currently, there are four small motor vehicle manufacturers in the United States. Table X-2 provides information about the 4 small domestic manufacturers in MY 2004. All are small manufacturers, having less than 1,000 employees.

Table X-1
Small Vehicle Manufacturers

Manufacturer	Employees	Estimated Sales	Sale Price Range	Est. Revenues*
Avanti	22	13	$25,000 to $63,000	$572,000
Panoz	50	150	$90,000 to $125,000	$16,125,000
Saleen	150	1,000	$39,000 to $59,000	$49,000,000
Shelby	44	60	$42,000 to $135,000	$5,310,000

* Assuming an average sales price from the sales price range.

The easiest and least expensive way for these manufacturers to meet the requirements of the final rule is to have a combination head/thorax side air bag that deploys from the side of the seat. This causes less disruption relating to vehicle design than the window curtain, which is stowed along the roof rail. The wide combination head/thorax side air bag is estimated to cost $121 for two per vehicle. Compared to the least expensive vehicle in Table X-2, the cost is less than one-half of one percent ($121/$25,000 = .00484). Compared to a weighted average sales price ($58,000), the cost is about 2 tenths of one percent ($121/$58,000 = .00209).

We believe that the market for the products of these small manufacturers is highly inelastic. Purchasers of these products are enticed by the desire to have an unusual vehicle. Furthermore, the price of competitors models will also need to be raised by a similar amount, since all light vehicles must pass the standards. Thus, we do not believe that raising the price to include the value of a combination head/thorax side air bag will have much, if any, affect of vehicle sales. We also anticipate these price increases will be passed on to the final customer.

Based on this analysis, the agency believes that the final rule will not have a significant economic impact on the four small domestic manufacturers.

Final-stage manufacturers and alterers

Several hundred second-stage or final-stage manufacturers and alterers could be impacted by the final rule. These manufacturers buy incomplete vehicles or add seating systems to vehicles without seats, or take out existing seats and add new seats. Many of these vehicles are van conversions, but there are a variety of vehicles affected. However, the entities will not be significantly affected by the rule. The technology is readily available for these manufacturers to use in their vehicles.[135] The final-stage manufacturer or alterer may purchase a seat that has a combination seat-mounted thorax/head air bag system and install the system as directed by the seat manufacturer. In addition, if they were to obtain a vehicle that has a roof-mounted air curtain, they could pass-through the certification of the manufacturer of the air bag system to the head protection requirements. The final-stage manufacturers and alterers may need to use the engineering judgment of the incomplete vehicle manufacturer, complete vehicle manufacturer, seat designer, and/or air bag supplier in certifying compliance, and may possibly work with others to perform some exemplar tests to demonstrate compliance. However, these approaches are unlikely to engender significant economic impacts and are similar to the procedures the entities already undertake with regard to certifying compliance with other FMVSSs, e.g., FMVSS No. 208, "Occupant Crash Protection" (frontal air bag systems). We also note that this final rule provides alterers and multi-stage vehicle manufacturers an extra year of lead time to

[135] The rule will affect the entities only if they change the side structure or seats in the vehicle. If they raise the roof of the vehicle, the vehicle is excluded from the pole test. If the side structure is not affected and the seats remain in the vehicle, then the original manufacturer's certification should be able to be passed-through by the final-stage manufacturer or alterer.

accommodate any necessary changes.[136] Between now and that date, 7 years from now, they can work with manufacturers of incomplete and complete vehicles to develop seat-mounted SIABs and other technologies that would enable them to install SIABs in their vehicles. Accordingly, while there are a number of final stage manufacturers and alterers impacted by the final rule, we do not believe the impact on them will be economically significant.

Dummy manufacturers, air bag manufacturers, air bag sensor manufacturers, and seating systems manufacturers

There are several manufacturers of dummies and/or dummy parts, some of which are considered small businesses. The final rule could have a positive impact on these types of small businesses by increasing demand for dummies. However, because crash test dummies are already used to meet FMVSS No. 214 (the ES-2re will only be used in place of the SID) and voluntary industry practices (the SID-IIs is used to assess conformance to the voluntary commitment to install SIABs), the impact will not be significant.

The agency does not believe that there are any small air bag manufacturers, and only a few small air bag sensor manufacturers. The final rule may have a positive impact on their businesses, but the impact might not be significant given that SIABs are already being installed in the vehicle fleet. We expect additional business for air bag manufacturers, air bag sensor manufacturers, and manufacturers of seating systems. The final rule will require the use of more air bags, and air bag sensors. We would expect more side air bags to be installed in outboard seating positions. In each case the final rule means positive business for these manufacturers.

[136] This accords with the amendments set forth in the agency's final rule on "Vehicles Built in Two or More Stages," 70 FR 7414, February 14, 2005, Docket 5673. The February 14, 2005 final rule also added a new process under which intermediate and final-stage manufacturers and alterers can obtain temporary exemptions from dynamic performance requirements (49 CFR Part 555).

However, since side air bag systems are already being installed in vehicle pursuant to voluntary industry practices, we do not expect that the impacts of this rule will be significant.

NHTSA knows of approximately 21 suppliers of seating systems, about half of which are small businesses. Seats containing SIABs will increase in cost, but the cost will likely be passed on to the consumer. NHTSA believes that air bag manufacturers will provide the seat suppliers with the engineering expertise necessary to meet the new requirements.

Aftermarket businesses

The Specialty Equipment Market Association (SEMA) believed that "aftermarket equipment manufacturers and other entities that diagnose, service, repair and upgrade motor vehicles" may be affected by the final rule if their installed products interact with equipment or systems used by vehicle manufacturers to meet the FMVSS No. 214 requirements. SEMA's comment focused on three issues. The following discusses those comments and our responses thereto.

a. SEMA said that, with regard to frontal air bags and air bag sensors installed pursuant to FMVSS No. 208, "Occupant crash protection," manufacturers of aftermarket leather and fabric seating products frequently have not had access to electronic information about the frontal air bag sensor in the vehicle seat. Consequently, SEMA stated, the aftermarket manufacturer or installer could not reprogram the sensor after the product has been installed, and in many instances, had to return the vehicle to the dealership for reprogramming. SEMA suggested that NHTSA should –

> make sure that electronic data is open and available in such a way so as not to preclude installation, servicing, or repair of legal aftermarket equipment…Specifically, SEMA believes it is appropriate to follow the EPA [Environmental Protection Agency] OBD [on-board diagnostic system] precedent in that any and all electronic data, or any that can be accessed through the available technology, must be made available to the vehicle owner to the extent that such access is available to other parties. Further, SEMA believes

> it is appropriate that NHTSA consider setting standards for data retrieval communication protocols, connectors and tools, and that such information and tools be made available to the public in a timely and cost-effective manner.

Agency response: Requiring vehicle manufacturers to ensure that electronic information about the SIABs is “open and available…so as not to preclude installation, servicing, or repair” of aftermarket equipment is beyond the scope of this rulemaking. Furthermore, such a requirement is not necessary or appropriate at this time. SEMA did not provide evidence that vehicle manufacturers will not make necessary repair and servicing information available to the aftermarket sales industry and to the service industry to the extent reasonable. Vehicles currently include many complex systems, and although dealer involvement may be necessary in some cases, the marketplace has generally made available sufficient information to permit convenient maintenance and repair of such systems. We do not believe that SIAB technology will prove any different in this regard. Further, we are not requiring vehicle manufacturers to share all electronic data with the vehicle owner. Such a requirement is unnecessary for the reasons discussed above, and is also undesirable because consumers are likely to find such highly technical information confusing and of little direct usefulness. Accordingly, we will not further consider for this final rule SEMA’s suggestion to compel vehicle manufacturers to share electronic data with the vehicle owner or to consider standards for data retrieval communication protocols.

b. SEMA stated that many dealerships have received service bulletins from the vehicle manufacturer warning them against the installation of aftermarket seat covers, citing concern that installation may interfere with front seat airbag sensors. SEMA suggested that NHTSA should “issue a regulation or policy statement which states that it is illegal to issue service bulletins or other communications that warn dealers about potential warranty denial based on the mere presence or installation of aftermarket equipment."

Agency response: The nature of communications between manufacturers and dealers on warranties is beyond the scope of this rulemaking and is not a matter with which this agency is normally involved. In the absence of notice for the issue, the commenter's showing of a safety need for the requested action, or the commenter's consideration of the appropriate role of the agency in banning communications from manufacturers to dealers, NHTSA declines the commenter's suggestion to issue the requested regulation or policy statement.

c. SEMA believed that NHTSA did not consider all of the small businesses potentially impacted by the final rule. The commenter believed that the rule "will directly affect a number of small entities including manufacturers and installers of seating equipment, interior upholstery, sunroofs and running boards. Beyond that, there are potentially thousands of small entities that may have the opportunity to diagnose, service, repair and upgrade motor vehicles." SEMA stated, "While it may be possible to work with the air bag manufacturers to design seating equipment, upholstery, sunroofs, running boards and other items of equipment that may effect [sic] air bag sensors, the information is of little value if the vehicle's computer system needs to be reprogrammed to accommodate the new equipment. The reg-flex analysis does not take into account that the vehicle manufacturers are the source of this information, not the air bag manufacturers. Unless such service information is forthcoming, thousands of small businesses may be directly impacted by the rule change."

Agency response: Manufacturers of seating equipment, upholstery, running boards and similar equipment that cannot independently assess whether their products will affect original SIAB systems can collaborate with air bag and vehicle manufacturers to make that assessment or can collaborate to develop products that are compatible with the SIABs.[137] We believe that the aftermarket installers of the products can also work with the air bag and vehicle manufacturers to ensure that the installation is compatible with the vehicles' SIAB systems. These aftermarket businesses already service vehicles with SIABs and other complex systems that use computer technology. Although vehicle dealer involvement may be necessitated in some cases, we do not believe that the involvement will result in a significant economic impact on the businesses. The marketplace has generally made available sufficient information to permit the aftermarket installation of equipment, and the maintenance and repair of vehicles with SIAB and other systems. There is no indication that vehicle manufacturers and dealers will not make necessary information reasonably available to the aftermarket sales and service industries. For the aforementioned reasons, we believe that this rule will not have a significant negative economic impact on a substantial number of those small entities.

- **A description of the projected reporting, recording keeping and other compliance requirements of a final rule including an estimate of the classes of small entities which will be subject to the requirement and the type of professional skills necessary for preparation of the report or record**.

For the oblique pole and MDB tests, the agency is requiring a phase-in schedule starting in 2 years. The phase-in schedule is set forth below in Table X-2. Credits will be allowed for early compliance, applicable to the 20 percent, 50 percent and 75 percent phase-in requirements.

As with previous rules, the agency will allow manufacturers that produce two or fewer lines the option of omitting the first year of the phase-in, if they achieve full compliance in the

[137] For example, see February 15, 2007 letter from Walser Industry to NHTSA regarding Walser's aftermarket car seat covers that are designed to be compatible with seat-mounted air bags. Docket 17694.

second year. Furthermore, vehicles manufactured in two or more stages and altered vehicles do not have to comply until one year after all vehicles have to comply.

For the small domestic automobile manufacturers, the reporting requirements depend upon the phase-in option taken. If they choose a phase-in, then there are reporting requirements to show compliance with the phase-in schedule. If they choose to meet the standard with all models in the second year of the phase-in, then there are no reporting requirements. The information to be reported would be developed by management, while an administrative assistant might type up and fill out the report.

Final-stage manufacturers and alterers need not meet the standard until the end of the phase-in period, thus there are no reporting requirements for them.   There are no reporting requirements for air bag manufacturers, air bag sensor manufacturers, dummy manufacturers, or manufacturers of seating systems. The reporting requirements are only applicable to vehicle manufacturers.

Table X-2
Final Rule Phase-In Schedule

Phase-in Date	Percent of each manufacturer’s light vehicles that must comply during the production period
September 1, 2009 to August 31, 2010	20 percent (excluding vehicles GVWR > 8,500 lbs.)
September 1, 2010 to August 31, 2011	50 percent vehicles (excluding vehicles GVWR > 8,500 lbs.)
September 1, 2011 to August 31, 2012	75 percent vehicles (excluding vehicles GVWR > 8,500 lbs.)
September 1, 2012 to August 31, 2013	All vehicles including limited line vehicles, except vehicles with GVWR > 8,500 lbs., alterers, and multi-stage manufacturers
On or after September 1, 2013	All vehicles, including vehicles with GVWR > 8,500 lbs., alterers and multi-stage manufacturers

- **<u>An identification, to the extent practicable, of all relevant Federal rules which may duplicate, overlap, or conflict with the final rule</u>**

We know of no Federal rules which duplicate, overlap, or conflict with the final rule.

- **<u>A description of any significant alternatives to the final rule which accomplish the stated objectives of applicable statutes and which minimize any significant economic impact of the final rule on small entities</u>**.

The additional year of lead time afforded to small entities minimize the impacts of the final rule on small entities. Additionally, the final rule is written as a performance standard, rather than a design standard. Thus, manufacturers, including small entities, have flexibility in developing countermeasures to meet the performance requirements of today's final rule.

B. Unfunded Mandates Reform Act

The Unfunded Mandates Reform Act of 1995 (Public Law 104-4) requires agencies to prepare a written assessment of the costs, benefits, and other effects of proposed or final rules that include a Federal mandate likely to result in the expenditures by States, local or tribal governments, in the aggregate, or by the private sector, of more than $100 million annually (adjusted annually for inflation with base year of 1995). Adjusting this amount by the implicit gross domestic product price deflator for the 2004 results in $118 million (108.237/92.106 = 1.13). The assessment may be included in conjunction with other assessments, as it is here.

A final rule on head and side air bags is not likely to result in expenditures by State, local or tribal governments of more than $100 million annually. However, it is estimated to result in the expenditure by automobile manufacturers and/or their suppliers of more than $118 million annually. Since the final rule allow a variety of methods to comply, which have a variety of costs ranging from an average of at least $78 per vehicle for 17.0 million vehicles, it will easily exceed $118 million. The final cost will depend on choices made by the automobile manufacturers. Chapter IX of the FRIA discusses four alternative regulatory approaches to the oblique pole test that we considered: (1) using the 90 degree pole test set forth in FMVSS No. 201; (2a) Using the IIHS barrier as the MDB barrier; (2b) using the Voluntary Commitment approach (perpendicular moving barrier test with one test dummy); and (c) applying a pole test to front and rear seats. The agency believes that it has selected the most cost-effective alternative that achieves the objectives of the rulemaking.

These effects have been discussed in this Final Regulatory Impact Analysis. Please see Chapter VI on Costs.

C. Market Failure or Other Specific Problem

Executive Order 12866 requires that all new federal regulations specify the market failure or other specific problem that will be addressed by the rulemaking. A market failure occurs when the market fails to allocate scarce resources to their highest-valued uses. This can occur for several reasons, such as market power, externalities, or information problems. (OMB Circular A-4 describes each of these in detail. See http://www.whitehouse.gov/omb/circulars/a004/a-4.pdf). Normally in competitive markets, exchanges between self-interested buyers and sellers will allocate resources to their highest valued uses.

To a certain extent the market for side impact air bags is working. Based on manufacturers' plans for MY 2011, an estimated 93 percent of the passenger cars and SUV & light trucks will be equipped with head side air bags, and almost 75 percent will be equipped with thorax side air bags. These product plans may also reflect a 2005 Congressional mandate, the "Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users," (SAFETEA-LU), P.L. 109-59 (Aug. 10, 2005; 119 Stat. 1144), Section 10302(a), that requires NHTSA to "complete" a rulemaking, presumably the FMVSS 214 pole test rulemaking, to enhance side impact protection no later than July 1, 2008.

In the case of side impact air bags the agency has no way of knowing whether fleet penetration might eventually rise to near 100 percent. However, manufacturer plans do not indicate this will happen through MY 2011. In the meantime, lives can be saved by regulating a side impact pole test as described in this analysis.

A potential market failure is the lack of knowledge on the part of consumers to differentiate between side air bags. Potential vehicle purchasers may pay attention to manufacturers' advertisements or NHTSA provided consumer information on which vehicles have side air bags. But at this point, consumers might not distinguish between head side air bags and thorax side air bags and consumers do not know, for example, that side impact air bags required by this standard will be larger than those that would be installed by the industry in the absence of a requirement, ensuring more coverage for occupants represented by the 5th percentile female test dummy and by the 50th percentile male dummy. The benefits estimated in this analysis result from the addition of side air bags and the widening of side air bags over and above the manufacturers' plans.

The agency is also considering adding a side pole test to its NCAP (New Car Assessment Program) ratings. However, the NCAP ratings do not reach all potential vehicle purchasers. In any event, we are required by statute to issue a side impact regulation.

XI. SENSITIVITY ANALYSES

A. Introduction

This section discusses the change in costs and benefits that result from different assumptions used in the analysis. When inputs that affect the analysis are uncertain, the agency makes its best judgment about the probable values or range of values that will occur. This analysis will examine alternatives to these selections to illustrate how sensitive the results are to the values initially selected.

The factors that will be examined include the cost of side impact sensors, the effectiveness of countermeasures at different impact speeds, the use of a minimum performance air bag, the installation rate of various types of air bag systems, and a value of $5.5 million per statistical life in valuing reductions in premature fatalities.

B. Sensitivity Factors

(1) <u>Side impact sensor costs</u>. The agency has teardown studies of five side impact air bag systems. Four of these systems have two sensors (one per side of the vehicle) and one system has four sensors (two per side of the vehicle). Whether manufacturers can meet the oblique impact test with two sensors, and still provide adequate coverage for the rear seat (even though the final rule does not require coverage for the rear seat) without four sensors is questionable. The unit costs of two sensors and the parts list for those sensors are significantly different between the air bag systems analyzed in teardown studies. The estimated cost of two sensors ranges from $36.67 to $100.80 (2004 economics). These costs are higher than the agency's estimates of the costs of two satellite frontal impact sensors of about $26. In the FRIA, the

agency assumes that the costs of two side impact sensors will decrease to an average cost of $36.67, and provides cost estimates assuming either two or four sensors will be needed per vehicle. If the $100.80 sensor cost is used, the cost for each air bag system would increase greatly, as shown below:

Table XI-1
Costs for Air Bag System with $100.80 for 2 Sensors

Air Bag System	Total Incremental Cost (Millions)*	Average Incremental Cost Per Vehicle
Combo:	$496	$29.16
Curtain + Thorax with 2 sensors:	$626	$36.85
Curtain + Thorax with 4 sensors:	$2,127	$66.12

* Present value

With the $100.80 sensor cost, the cost per equivalent life saved would increase to $2.3 million for the combo, $2.6 million for the curtain with 2-sensors and $8.7 million for the curtain with 4 sensors (with 7% discount).

(2) Effectiveness of the countermeasures at different impact speeds. The agency has tested both the combination head/thorax air bag and the separate window curtains with thorax air bags at 18 mph perpendicular, 20 mph oblique pole and 30 mph oblique pole. The results show that the devices are very effective in the 20 mph pole test, which produces a vehicle lateral delta V of 19 mph[138]. In the FRIA, we are assuming that the device has full effectiveness in the 12 to 25 mph vehicle delta V range. Twelve mph was chosen as a likely deployment threshold in side impacts, although some designs may be set at lower speeds. We know that there will be a drop off in effectiveness as delta V gets higher and the air bag bottoms out. To further understand how the effectiveness varies with the vehicle delta-V, we examined three cases: head-to-narrow object impacts, head-to-front of the striking vehicles impacts, and head-to-vehicle interior components.

[138] 20.0 mph times the cosine of 15 degrees is 19.3 mph.

(A) For head impacts with a narrow object crashes, we estimate that the deployed HIC scores would be as low as about 200 and as high as about 850 in the 12 –25 delta-V range, as shown below:

Table XI-2
Estimated Deployed HIC scores

Delta-V (mph)	12	16.78	18	19	20	23	25
Combo bag	N/A	140	180	213	246	344	410
AC	N/A	135	296	427	559	955	1,218
Pendulum, AC	202	467	534	589	645	810	921
Avg HIC	202	247	337	410	483	703	850

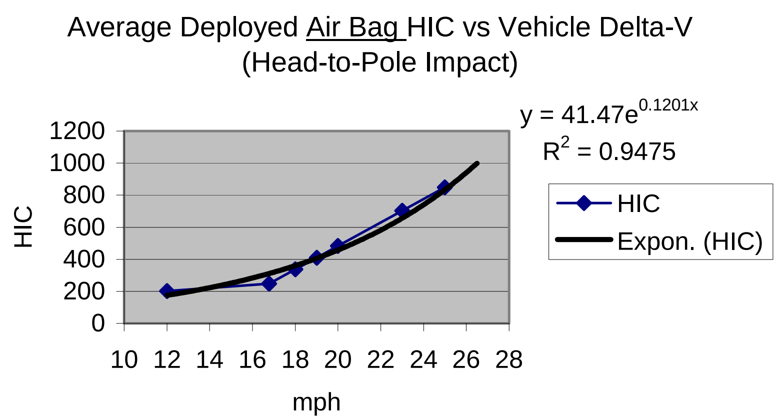

Figure XI-1. Estimated HIC Scores, Head-to-Pole

As discussed in the test data section (Chapter IV), severe head injuries would occur when the head of an occupant impacts with a pole or tree (as in the oblique pole test). However, in the delta-V range, the deployed HIC scores show that head bags are equally effective, regardless of impact speed, as shown below:

Table XI-3
Effectiveness vs. Delta-V
Head-to-Pole Impacts

Delta-V (mph)	Baseline HIC	Deployed HIC	Fatal
12	4,577	175	100.00%
18	6,866	361	100.00%
19	10,554	407	100.00%
20	14,242	459	100.00%
23	25,306	658	99.99%
25	32,682	837	99.96%

The head air bag effectiveness rates, with respect to delta-V, show that the effectiveness would be insensitive with respect to delta-V in the 12 –25 mph delta-V range.

(B) For the head-to-front of striking vehicle, the following effectiveness was estimated:

Table XI-4
Head Bag Effectiveness With Respect To Delta-V
Head-to-Front of Striking Vehicle

Delta-V (mph)	Baseline HIC	Deployed HIC	AIS 3	AIS 4	AIS 5	Fatal
12	659	178	90.54%	91.19%	94.33%	97.11%
13	795	200	92.02%	93.31%	96.22%	98.36%
14	958	224	92.94%	95.17%	97.72%	99.20%
15	1,155	252	92.83%	96.55%	98.77%	99.67%
16	1,392	283	90.53%	97.31%	99.40%	99.89%
17	1,678	319	81.38%	97.07%	99.69%	99.97%
18	2,023	358	41.78%	93.48%	99.73%	99.99%
19	2,438	402	0.00%	62.17%	98.86%	100.00%
20	2,939	452	0.00%	0.00%	61.74%	100.00%
21	3,543	508	0.00%	0.00%	0.00%	99.99%
22	4,270	571	0.00%	0.00%	0.00%	99.99%
23	5,148	642	0.00%	0.00%	0.00%	99.99%
24	6,205	722	0.00%	0.00%	0.00%	99.98%
25	7,479	811	0.00%	0.00%	0.00%	99.96%

For the 12- 25 mph delta-V range, the maximum, minimum and average HIC scores were estimated, based on the results in Table XI-4, as shown below:

Table XI-5
Maximum, Minimum and Average Effectiveness

	AIS 3	AIS 4	AIS 5	Fatal
Maximum effectiveness rate	92.94%	97.31%	99.73%	100.00%
Minimum effectiveness rate	41.78%	62.17%	61.74%	97.11%
Average effectiveness rate	83.14%	90.78%	94.05%	99.58%

Head injuries when the head impacts with the striking vehicle in vehicle-to-vehicle side crashes are shown below:

Table XI-6
Head Injuries in Head-to-Front of Striking Vehicle

Occupants	AIS 3	AIS 4	AIS 5	Fatal
50th	189	89	43	222
5th	63	30	14	74
Total	252	118	58	296

(1) If we assume all crashes occurred at a delta-V of 12 mph, head bags would save 278 equivalent lives, as shown below:

Table XI-7
Equivalent Live Saved
If All Crashes Occurred At 12 mph

	AIS 3	AIS 4	AIS 5	Fatal	Total
Target population (50th)	189	89	43	222	
Effectiveness	90.54%	91.19%	94.33%	97.11%	
Benefits	171	81	41	216	509
Equivalent life conv. Factor	0.0916	0.2153	0.7124	1	
Equivalent life saved	15.686	17.3795	29.1480	215.59	278

(2) If we assume all crashes occurred at a delta-V of 18 mph, head bags would save 278 equivalent lives, as shown below:

Table XI-8
Equivalent Lives Saved
If All Crashes Occurred At 18 mph

	AIS 3	AIS 4	AIS 5	Fatal	Total
Target population (50th)	189	89	43	222	
Effectiveness	41.78%	93.48%	99.73%	99.99%	
Benefits	79	83	43	222	427
Equivalent life conv. Factor	0.0916	0.2153	0.7124	1	
Equivalent life saved	7.2383	17.8170	30.8177	221.98	278

(3) Benefit estimate made with the 20 mph bag effectiveness, head bags would save 241 equivalent lives, as shown below:

Table XI-9
Equivalent Live saved
If All Crashes Occurred At 20 mph

	AIS 3	AIS 4	AIS 5	Fatal	Total
Target population (50th)	189	89	43	222	
Effectiveness	0.00%	0.00%	61.74%	100.00%	
Benefits	0	0	27	222	249
Equivalent life conv. Factor	0.0916	0.2153	0.7124	1	
Equivalent life saved	0	0	19.0777	221.99	241

The total equivalent lives saved above show that the use of the 20 mph effectiveness rate would not significantly affect the estimate on fatal head injuries. However, the estimate based on the 20 mph HIC scores would underestimate the AIS 3, 4 and 5 head injury benefits, if estimates were made with HIC results from 18 mph or 12 mph.

(C) Head impacts with vehicle interior components (vehicle-to-pole/tree or vehicle-to-vehicle/others):

Table XI-10
Head Impacts with Vehicle Interior Components
Baseline and Deployed HIC scores

Delta-V (mph)	Baseline HIC	Deployed HIC	AIS 3	AIS 4	AIS 5	Fatal
12	508	214	78.14%	78.44%	83.43%	89.01%
13	544	224	79.20%	79.71%	84.77%	90.25%
14	581	236	80.26%	81.01%	86.12%	91.44%
15	622	247	81.29%	82.34%	87.47%	92.58%
16	665	260	82.29%	83.67%	88.79%	93.65%
17	711	273	83.22%	85.00%	90.07%	94.64%
18	760	286	84.06%	86.30%	91.30%	95.54%
19	813	301	84.78%	87.56%	92.47%	96.35%
20	869	316	85.36%	88.76%	93.55%	97.06%
21	929	332	85.74%	89.88%	94.55%	97.68%
22	994	348	85.89%	90.90%	95.45%	98.20%
23	1,062	366	85.73%	91.82%	96.25%	98.63%
24	1,136	384	85.17%	92.60%	96.94%	98.99%
25	1,215	403	84.07%	93.24%	97.54%	99.26%

Table XI-11
Maximum, Minimum and Average Effectiveness Rates

	AIS 3	AIS 4	AIS 5	Fatal
Maximum effectiveness rate	85.89%	93.24%	97.54%	99.26%
Minimum effectiveness rate	78.14%	78.44%	83.43%	89.01%
Average effectiveness rate	83.23%	86.52%	91.34%	95.23%

Table XI-12
Injury Population

Occupant	AIS 3	AIS 4	AIS 5	Fatal
50th	159	74	34	121
5th	53	25	11	40
Total	212	98	45	161

(1) If we assume all crashes occurred at a delta-V of 12 mph:

Table XI-13
At Delta-V of 12 mph, 50^{th} Occupants

	AIS 3	AIS 4	AIS 5	Fatal	Total
Target population (50th)	159	74	34	121	
Effectiveness	78.14%	78.44%	83.43%	89.01%	
Benefits	124	58	28	108	318
Equivalent life conv. Factor	0.0916	0.2153	0.7124	1	
Equivalent life saved	11.4	12.5	20.0	117.5	151

(2) If we assume all crashes occurred at a delta-V of 25 mph:

Table XI-14
At Delta-V of 25 mph, 50th Occupants

	AIS 3	AIS 4	AIS 5	Fatal	Total
Target population (50th)	159	74	34	121	
Effectiveness	84.07%	93.24%	97.54%	99.26%	
Benefits	134	69	33	120	236
Equivalent life conv. Factor	0.0916	0.2153	0.7124	1	
Equivalent life saved	12.2	14.8	23.4	119.9	170

(3) Benefit estimate made with the 20 mph bag effectiveness:

Table XI-15
At Delta-V of 20 mph, 50th Occupants

	AIS 3	AIS 4	AIS 5	Fatal	Total
Target population (50th)	159	74	34	121	
Effectiveness	85.36%	88.76%	93.55%	97.06%	
Benefits	136	66	32	117	234
Equivalent life conv. Factor	0.0916	0.2153	0.7124	1	
Equivalent life saved	12.4	14.1	22.5	117.3	166

The analysis above shows that it would be reasonable to estimate the benefit estimate based on the HIC scores measured at a delta-V of 20 mph.

(3) <u>Minimum Performance Requirement</u>: The benefit estimation was based on an average performance of current air bags tested[139], and the performance was based on the relatively small sample size used in our feasibility pole test program. Since the vehicles were not randomly selected for the feasibility test, performance of these air bags may not represent characteristics of head & thorax bags in real world crashes. The feasibility study shows that air bags that met the

139 For the analysis, we did not differentiate air bag types. Since different types of air bags would result in different levels of protection, the change in air bag distribution would affect the average/overall performance of the bags. In addition, vehicle types were not considered for the bag performance. In other words, we assumed that a particular air bag would produce the same reduction in injury level, regardless of vehicle type.

requirements produced lower injury scores than the injury criteria. Since the injury criteria requirement levels are higher than the injury scores we have seen with the air bags in the pole tests, manufacturers could design their bags to just meet the minimum performance requirement. These "hypothetical minimum performance" head and thorax air bags would reduce the expected benefits that were based on the air bags we tested.

(A) For head injuries from head-to-pole/tree impacts, the passes (about 500 HIC scores) and fails (8,000 – 14,000 HIC scores) are so extreme that the analysis would provide practically the same fatality finding. In other words, countermeasures designed for meeting the final rule at 1,000 HIC would also be equally effective as ones designed to meet the requirement, for example, at 500 HIC[140] in preventing fatal head injuries.

Table XI-16
Head-to-Pole Impact
Bag Effectiveness, Actual vs. Minimum Performance

	Deployed HIC	AIS 3	AIS 4	AIS 5	Fatal
Actual, measured:	504	10.01%	2.62%	0.23%	0.01%
Minimum:	1,000	36.31%	14.60%	2.23%	0.11%
	Baseline HIC	AIS 3	AIS 4	AIS 5	Fatal
Actual, measured:	14,242	0.00%	0.00%	0.00%	100.00%
	Effectiveness	AIS 3	AIS 4	AIS 5	Fatal
Actual, measured:		N/A	N/A	N/A	99.99%
Minimum:		N/A	N/A	N/A	99.89%

The results in Table XI-16 show that the effectiveness rates are practically equal, whether the minimum or the actual HIC scores are used.

[140] Without head air bags, HIC ranges from approximately 8,000 to 14,000. At these HIC levels, risk of fatal injury is close to 100%. At 500 HIC level, there are 10 % of AIS 3, 3% of AIS 4, 0% of AIS 5 and 0% of fatal injury risks. At 1,000 HIC level, there are 36% of AIS 3, 14.6% of AIS 4, 2.2% of AIS 5 and 0.0% of fatal injury risks. Thus, air bags are equally effective in preventing fatal injuries whether deployed air bags result in a HIC of 500 or 1,000.

(B) For head injuries from head-to-vehicle interior component impacts, we compare the actual HIC scores with the hypothetical HIC 1,000. The actual HIC scores with deployed head air bags are shown below:

Table XI-17
Actual HIC Scores and Associated Injury Risk
With Deployed Head Bags
Head-to-Vehicle Interior Components

Delta-V (mph)	HIC	AIS 3	AIS 4	AIS 5	Fatal
12	214	2.23%	0.57%	0.04%	0.00%
13	224	2.42%	0.62%	0.04%	0.00%
14	236	2.63%	0.68%	0.05%	0.00%
15	247	2.85%	0.73%	0.05%	0.00%
16	260	3.09%	0.79%	0.06%	0.00%
17	273	3.35%	0.86%	0.06%	0.00%
18	286	3.64%	0.93%	0.07%	0.00%
19	301	3.95%	1.01%	0.07%	0.00%
20	316	4.29%	1.10%	0.08%	0.00%
21	332	4.67%	1.20%	0.09%	0.00%
22	348	5.08%	1.30%	0.10%	0.00%
23	366	5.54%	1.42%	0.11%	0.00%
24	384	6.04%	1.55%	0.12%	0.00%
25	403	6.60%	1.70%	0.14%	0.00%

Table XI-18
Minimum HIC and Associated Injury Risk
With Deployed Head Bags, Head-to-Vehicle Interior Components

Delta-V (mph)	HIC	AIS 3	AIS 4	AIS 5	Fatal
20	1,000	36.31%	14.60%	2.23%	0.11%

Table XI-19
Baseline HIC Scores and Associated Injury Risk
(Without Deployed Head Bags), Head-to-Vehicle Interior Components

Delta-V (mph)	HIC	AIS 3	AIS 4	AIS 5	Fatal
12	508	10.20%	2.67%	0.23%	0.01%
13	544	11.63%	3.07%	0.28%	0.01%
14	581	13.30%	3.56%	0.33%	0.01%
15	622	15.23%	4.15%	0.41%	0.01%
16	665	17.45%	4.86%	0.50%	0.02%
17	711	19.98%	5.74%	0.62%	0.02%
18	760	22.83%	6.82%	0.77%	0.03%
19	813	25.97%	8.15%	0.98%	0.04%
20	869	29.33%	9.80%	1.26%	0.05%
21	929	32.75%	11.83%	1.64%	0.07%
22	994	36.01%	14.33%	2.17%	0.11%
23	1,062	38.80%	17.36%	2.91%	0.16%
24	1,136	40.74%	20.97%	3.97%	0.25%
25	1,215	41.41%	25.11%	5.49%	0.39%

Table XI-20
Effectiveness with Actual HIC scores
Head-to-Vehicle Interior Components

Delta-V (mph)	AIS 3	AIS 4	AIS 5	Fatal
12	78.14%	78.44%	83.43%	89.01%
13	79.20%	79.71%	84.77%	90.25%
14	80.26%	81.01%	86.12%	91.44%
15	81.29%	82.34%	87.47%	92.58%
16	82.29%	83.67%	88.79%	93.65%
17	83.22%	85.00%	90.07%	94.64%
18	84.06%	86.30%	91.30%	95.54%
19	84.78%	87.56%	92.47%	96.35%
20	85.36%	88.76%	93.55%	97.06%
21	85.74%	89.88%	94.55%	97.68%
22	85.89%	90.90%	95.45%	98.20%
23	85.73%	91.82%	96.25%	98.63%
24	85.17%	92.60%	96.94%	98.99%
25	84.07%	93.24%	97.54%	99.26%

If a HIC score of 1,000 were measured at B pillar with a deployed head bag at a vehicle delta-V of 20 mph, a point benefit estimate made at a vehicle delta-V of 20 mph would result in "no" benefit for the head-to-B pillars impacts in side crashes. According to the benefit estimate made in the FRIA, head air bags would save about 184 lives in head-to-interior component impacts in vehicle-to-pole/tree and vehicle-to-vehicle/others side crashes (in a delta-V range of 12 –25 mph), as shown below;

Crashes	Front Occupants	Saved
Vehicle-to-pole/tree side crashes:	50th	21
	5th	7
Vehicle-to-vehicle/others side crashes:	50th	117
	5th	39
	Total	184

If these fatal benefits were excluded from the 214 FRIA (in other words, if a HIC score of 1,000 were measured at B pillar with a deployed head bag at a vehicle delta-V of 20 mph), the overall fatal benefits would be reduced by 23%, as shown below:

Front Occupants (near-side):	Saved
Lives Saved, with the actual deployed HIC:	799†
Lives Saved, with the hypothetical HIC 1,000:	615*
Percent reduction in benefit:	23%

† Potential lives saved by air bags, prior to adjustment made with installation rate & compliance rate.
* 799 – 184 = 615

The above derivation shows that when a point estimate is made with HIC scores at a delta-V of 20 mph, the hypothetical HIC 1,000 would reduce the fatal benefits by 23%, from 799 to 615, when compared to the estimate made with the actual HIC of 316.

Note that according to the 201 compliance test results, with 2003 model year vehicles, an average HIC of 625 was measured at the B pillar (at a vehicle delta-V of 20 mph). If a head air bag produces a HIC score of 1,000 at delta-V of 20 mph, the hypothetical bag would be much stiffer than the B pillar, in terms of HIC level (more than three times higher). However, based on the vehicles tested in the pole and MDB tests and the component tests performed by Volvo, we do not believe vehicle manufacturers would install such aggressive air bags.

The 50th chest deflection results in the oblique pole tests show an average chest deflection of 37.9 mm with thorax bags. In the tests, an average deflection of 48.7 mm was measured with vehicles that failed to meet the 44 mm requirement. If we assume all vehicles produce a chest deflection of 44 mm (i.e., minimum performance) rather than the actual 37.9 mm, it would result in a chest fatal benefit of 3 lives, as shown below:

Table XI-21a
Estimated Chest Benefits Vehicle-to-Pole/Tree Side Crashes
50th Occupants, Front Outboard, 12-25 mph
Effectiveness

	Deflection, mm	AIS 3+	AIS 4+	AIS 3
Failed to meet 44mm	49 (48.7)	56%	25%	31%
Min. Performance of 44 mm	44	51%	21%	29%
Effectiveness		10.04%	16.02%	5.18%

Table XI-21b
Benefits

	AIS 3	AIS 4	AIS 5	Fatality	Total
Target Population	91	86	0	18	
Effectiveness	5.18%	16.02%	16.02%	16.02%	
Benefits	5 (4.71)	14 (13.83)	0.00	3 (2.83)	21

The results in Table XI-21 show that the use of the minimum performance of 44 mm, rather than the actual chest deflection of 37.9 mm, with a baseline deflection of 49 mm (rather than the actual baseline of 40.7 mm) would increase the chest fatal benefit estimate from 2 lives saved (which was based on the actual thorax bag performance) to 3 lives saved for occupants represented by a 50th percentile male test dummy in vehicle-to-pole/tree side crashes in a vehicle delta-V range of 12 –25 mph.

For occupants represented by a 5th female test dummy, we estimate that thorax bags would not reduce the fatal chest benefits in vehicle-to-pole side crashes, in the 12 –25 mph range.

For the vehicle-to-vehicle/other case, we estimated that a total of 149 additional lives would be saved with thorax air bags for occupants in near outboard seating positions, annually. The MDB test results show that none of the vehicles with thorax bags failed the minimum performance requirement of 44 mm. Therefore, if we use the minimum performance requirements, hypothetically, the bags would not provide any benefits in vehicle-to-vehicle side crashes (12 – 25 mph).[141]

For abdominal and pelvic injuries, we have determined that thorax air bags would not provide any significant benefits in side crashes. Thus, whether air bags meet the minimum performance requirements or produce the same level of performance as the ones tested in the pole test, these bags would have a minimal effect on the estimated benefits.

As the above analysis shows, the reduction in benefits based on the minimum hypothetical performance air bag is relatively small when compared to the overall benefits based on the production bags tested, in terms of injuries prevented and lives saved. The minimal effect is due to the fact that the majority of the benefits result from head/facial injuries and head bags are highly effective in preventing head/facial injuries in side crashes.

(4) Air Bag Distribution: In Chapter V, we estimated the benefits based on three different head/thorax air bags systems: combo, curtain+thorax with 2 sensors and curtain+thorax with 4 sensors. The estimation is based on an assumption that all vehicles are equipped with only one type of air bag system. However, in reality, vehicle manufacturers have installed different types

[141] However, as discussed previously, the real world crash data show that thorax bags are effective when all side crashes are considered (approximately 12%).

of air bag systems in some of their vehicles. Since different air bag systems would have different effectiveness in side crashes, the distribution would affect the overall benefits.

Based on our 2004 FARS target population of 2,311 near side front outboard and 33 near side rear outboard occupants fatalities[142], we estimated combo air bags would save 266 additional lives for occupants in near-side seating positions, likewise, curtain+ thorax air bags with 4-sensors would save 311 additional lives, annually (among the total of 311 additional lives saved, 271 from the near-side and the remaining 40 were from the far-side). According to the 2011 side air bag distribution, there are 11,295,538 curtain+thorax air bags and 884,551 combo air bags. If we assume the distribution ratio (i.e., curtain+thorax/combo air = 11,295,538/884,551) remains unchanged when installed in the full fleet of vehicles, a total of 307 additional lives would be saved when both near-side and far-side occupants are considered, annually.[143]

(5) In Chapter VII, we used a value of $3.7 million in valuing reductions in premature fatalities. In valuing reductions in fatalities, we also examined a value of $5.5 million per statistical life as a sensitivity analysis. This represents a central value consistent with a range of values from $1 to $10 million suggested by recent meta-analyses of the wage-risk value of statistical life (VSL)

[142] 372 are from the front vehicle-to-pole/tree, 1,939 are from the front vehicle-to-vehicle/others, 4 are from the rear vehicle-to-pole/tree, and 29 are from the rear vehicle-to-vehicle/others.

[143] Additional benefits when both near-side and far-side occupants are considered, with the 2011 distribution rate:

Bag Type	No. of	Weighed	Additional Lives Saved	Weighed Benefits
AC+th	11,295,538	92.74%	311	288
Combo	884,551	7.26%	266	19
Total	12,189,989	100%		307

literature[144]. As shown in Chapter VII, multiplying the value of life by the equivalent lives saved derives total benefits. The net benefits are derived by subtracting total costs from the total benefits, as shown in Table XI-22.

Table XI-22
Net Benefits with a Value of $5.5M per Equivalent Life

Countermeasure	Benefits ($M)		Net Benefit ($M)	
	3%	7%	3%	7%
Combo + 2 sensors	$1,338	$1,063	$909	$634
Curtain + 2 sensors	$1,523	$1,210	$963	$650
Curtain + 4 sensors	$1,529	$1,215	$405	$91

144 Mrozek, J.R. and L.O. Taylor, What determines the value of a life? A Meta Analysis, Journal of Policy Analysis and Management 21 (2), pp. 253-270.

XII. PROBABILISTIC UNCERTAINTY ANALYSIS

This chapter identifies and quantifies the major uncertainties in the cost-effectiveness and net benefit (benefit-cost) analyses. Throughout the course of both the cost-effectiveness and net benefit analyses, many assumptions were made, diverse data sources were used, and different statistical processes were applied. The variability of these assumptions, data sources, and statistical processes potentially would impact the estimated regulatory outcomes. These assumptions, data sources, and derived statistics all can be considered as uncertainty factors for the regulatory analysis. The purpose of the uncertainty analysis is to identify the uncertainty factors with appreciable variability and quantify them by their probability distributions. Values from these distributions are then randomly selected and fed back to the cost-effectiveness and net benefit analysis process using the Monte Carlo statistical simulation technique[145]. The simulation technique induces the probabilistic outcomes accompanied with degrees of probability or plausibility. This facilitates a more informed decision-making process.

The analysis starts by establishing mathematical models that imitate the actual processes in deriving cost-effectiveness and net benefits, as shown in previous chapters. Each variable (e.g., cost of technology) in the mathematical models represents an uncertainty factor that would potentially alter the model outcomes if its value were changed. Variations of these uncertainty factors are described by appropriate probability distribution functions based on available data. If

[145] a: Robert, C.P. & Casella, G., *Monte Carlo Statistical Methods*, Springer-Verlag New York, Inc., 1999

b: Liu, J.S., *Monte Carlo Strategies in Scientific Computing*, Springer-Verlag New York, Inc., 2001
(Or any statistics books describing the Monte Carlo simulation theory are good references for understanding the technique.)

data are not sufficient or not available, professional judgments are used to estimate the distribution of these uncertainty factors.

After defining and quantifying the uncertainty factors, the next step is to simulate the model to obtain probabilistic results rather than single-value estimates. The simulation process is run repeatedly. Each complete run is a trial. For each trial, the simulation first randomly selects a value for each of the uncertainty factors based on their probability distributions. The selected values are then fit into the models to forecast results. The simulation repeats the trials until certain pre-defined criteria[146] are met and a probability distribution of results is generated.

A commercially available software package, Crystal Ball from Decisoneering, Inc., was used for this purpose - building models, running simulations, storing results, and generating statistical results. Crystal Ball is a spreadsheet-based risk analysis software which uses the Monte Carlo simulation technique to forecast results. In addition to the simulation results, the software also estimates the degree of certainty (or confidence, or credibility). The degree of certainty provides the decision-maker an additional piece of important information to evaluate the forecast results.

[146] The pre-defined criteria may change with each uncertainty analysis. In this case, we require a 99 percent precision in mean for each simulated outcome such as total costs, cost-effectiveness, and net benefits as described later.

A. Simulation Models

Mathematical models were built to imitate the process used in deriving cost-effectiveness and net benefits as developed in previous chapters. Both the cost-effectiveness and net benefit models comprise two principal components: benefits and costs. In the cost-effectiveness model, benefits are represented by fatal equivalents (FEs) avoided. In the net benefit model, benefits are represented in dollars, which is the product of comprehensive cost per life saved and FEs. Since benefits (fatalities and injuries reduced) were already expressed as FEs in the cost-effectiveness model, the net benefit model is just one step removed from the cost-effectiveness model. Therefore, this analysis describes the benefit component of the cost-effectiveness and net benefit models and quantifies their uncertainty factors in one section. Then, in the subsequent section, the analysis discusses the cost component of the models and quantifies their uncertainty factors. Finally, the analysis presents and summarizes the simulated results for cost-effectiveness and net benefits.

A.1 Benefit Components

As described earlier, fatal equivalents (FEs) are the basic benefit measurement for both cost-effectiveness and net benefit models. The overall FEs comprise FEs derived from four mutually exclusive target populations: (1) near-side side impact, head injuries, (2) near-side side impact, chest injuries, (3) near-side side impact, pelvis/abdominal injuries, and (4) far-side side impacts, occupant fatalities. Each of the four FE components is derived through a series of processes:

(1) deriving initial injury benefits,

(2) adjusting the initial injury benefits to account for projected side air bag penetration rate, current air bag compliance rate, the air bag protection area, the impact of FMVSS No. 201, and the impact of electronic stability control (ESC) penetration,

(3) deriving the net injury benefits by redistributing the adjusted injury benefits from higher injury severity levels to lower severity level injuries,

(4) deriving FEs by multiplying the net injury benefits by their corresponding injury-to-fatality ratios, and

(5) discounting FEs to derive the net benefits over the vehicle's life.

This series of processes can be represented by the following generic, simplified mathematical model, with each of the parameters representing a matrix:

$$FEs = P * E * A * I * R * D \text{ (FE Model)}$$

Where, FEs = fatal equivalents

P = target population

E = effectiveness of side air bags against target population P

A = adjustment factors

I = injury redistribution factors

R = injury-to-fatality ratios

D = cumulative lifetime discount factors.

In more detail, P, the target population, is a 1x4 matrix and can be noted as

$$P = \begin{pmatrix} P_1 & P_2 & P_3 & P_4 \end{pmatrix}$$

Where, P_1 = fatalities,

P_2 = MAIS 5 injuries,

P_3 = MAIS 4 injuries, and

P_4 = MAIS 3 injuries.

The effectiveness E is a 4x4 matrix. Each entices e_i is the side air bag effectiveness against corresponding target population $P_{i,}$, for i = 1 to 4:

$$E = \begin{pmatrix} e_1 & 0 & 0 & 0 \\ 0 & e_2 & 0 & 0 \\ 0 & 0 & e_3 & 0 \\ 0 & 0 & 0 & e_4 \end{pmatrix}$$

The product of P and E representing the initial injury benefits is equal to

$$P * E = \begin{pmatrix} P_1 * e_1 & P_2 * e_2 & P_3 * e_3 & P_4 * e_4 \end{pmatrix}$$

As shown, the first entices P_1*e_1 means the initial fatal benefits. The remaining entices of P*E separately represents the MAIS 5, MAIS 4, and MAIS 3 injury benefits.

The parameter A is a 1x1 matrix, which actually is the multiplication of five different adjustment factors. These five adjustment factors are the projected side air bag penetration rate in year 2011 (a_1), air bag passing rate (a_2), air bag protection area (a_3), the impact of FMVSS No. 201 (a_4), and the impact of ESC (a_5). A can be noted as:

$$A = \left((1-a_1*a_2) *a_3 *a_4 *a_5 \right).$$

Multiplying the initial injury benefits by the adjustment factor A derives the adjusted injury benefits (P*E*A).

The injury redistribution factor I is a 4x4 matrix and can be noted as:

$$I = \begin{pmatrix} 1 & -I_{12} & -I_{13} & -I_{14} \\ 0 & 1 & -I_{23} & -I_{24} \\ 0 & 0 & 1 & -I_{34} \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Where, I_{ij} represents the redistribution factor for injury severity i to a lower injury severity j, i<j with i=1 as fatalities and i=4 as MAIS 3 injuries. For example, I_{12} represents the portion of fatalities that is distributed to MAIS 5 injuries, I_{13} is the portion of fatalities distributed to MAIS 4 injuries, and so forth. The negative sign reflects that the redistributed benefits from higher severity injuries need to be excluded from the lower severity injuries to derive the net injury benefits.

Multiplying the adjusted injury benefits by redistribution factors derives the net injury benefits (P*E*A*I). For example, if the adjusted injury benefits are noted as

$B = (b_1, b_2, b_3, b_4)$, then the net injury benefits would be:

$$B*I = (b_1 \quad -b_1*I_{12}+b_2 \quad -b_1*I_{13}-b_2*I_{23}+b_3 \quad -b_1*I_{14}-b_2*I_{24}-b_3*I_{34}+b_4).$$

The first entices, b_1, represents the net fatal benefits. The second entices, $-b_1*I_{12}+b_2$, is the difference between MAIS 5 benefits (b_2) and the portion that was distributed from fatalities (b_1*I_{12}), and thus represents the net MAIS 5 injury benefits. The remaining two entices represent the net MAIS 4 and MAIS 3 benefits, respectively.

The element R, injury-to-fatal ratios, is a 4x1 matrix that contains the relative cost ratio of MAIS injuries to fatalities:

$$R = \begin{pmatrix} r_1 \\ r_2 \\ r_3 \\ r_4 \end{pmatrix}$$

Where, r_i is the cost ratio of severity i injuries to fatalities, $1 \le i \le 4$, with i=1 as fatalities, i=2 as MAIS 5 injuries, and so forth. The product of net benefits and injury-to-fatality ratios is FEs.

Finally, the discounting factor D is a 1x2 matrix:

$D = (d_1, d_2)$,

Where, d_1 = the 7 percent discount rate

d_2 = the 3 percent discount rate.

Applying these discount rates to FEs derives the benefits of rule for the 3 and 7 percent discount rates.

Uncertainty Factors

Each parameter in the above FE model represents a major category of uncertainty factors. Therefore, there are 6 basic categories of uncertainty factors that would impact the estimated benefit outcomes: target population (P), effectiveness (E), adjustment factors (A), injury redistribution factors (I), injury-to-fatality ratios (R), and cumulative lifetime discount factors (D).

Target population, P, is obviously important to benefit estimates because it defines the population of risk without the rule. The major uncertainties in this factor arise from sources such as demographic projections, driver/occupant behavioral changes (e.g., shifts in safety belt use), increased roadway travel, new Government safety regulations, and survey errors in NHTSA's data sampling system NASS-CDS.

The impact of demographic and driver/occupant behavior changes, roadway traveling, and new automobile safety regulations are reflected in the crash database. Thus, the analysis examined the historic FARS and CDS to determine whether variations resulting from these uncertainty sources would warrant further adjustment to the future target population. Based on 1998 to 2004 FARS, there is no definite trend for this period of time. The changes among years were small with a variation within $\pm$2.0 percent. Data from 1998-2004 CDS yields a similar result. Therefore, the analysis does not further adjust the target population to account for variations associated with these uncertainty sources. Only survey errors from CDS are considered here.

The size of the target population is treated as normally distributed. Survey errors for CDS are used as the proxy for standard deviation to establish the normal distribution. Generally, about 68 percent of the estimated target population is within one standard error (SE) of the mean survey population. The standard errors were derived using the formula[147]:

$$SE = e^{3.65254+0.04723\ln(x)^2}, \quad x = \text{estimated target injuries.}$$

<u>Effectiveness of countermeasures, E</u>, is by far the parameter with the greatest uncertainty. The sources of its uncertainty include the estimation errors inherent in the statistical processes used in deriving the effectiveness of head/thorax side air bags, the variability of the laboratory crash tests among vehicles, and the statistical variations of the injury risk probabilities. Since effectiveness was derived from two different methodologies and based on a variety of data sources, two

[147] 1995-1997 National Automotive Sampling System, Crashworthiness Data System, DOT HS 809 203, February 2001

approaches are used to address the variations. The first approach is for effectiveness that was developed using the real-world crash data and was accompanied with statistically derived confidence bounds (e.g., effectiveness for far-side occupant fatalities in side impact crashes). This type of effectiveness is treated as normally distributed. The initial confidence bounds are used as the proxy for standard deviations for establishing the normal distribution.

The second approach is for effectiveness that was derived from injury risk curves and laboratory crash test data. The variations for this type of effectiveness are sensitive to variations from both injury risk curves and laboratory test data. Variations for this type of effectiveness thus are more unpredictable than the effectiveness that was based on a single data source. Therefore, the analysis does not assign any probability distributions to these effectiveness rates. Instead, the generation of probability distributions for this type of effectiveness is built into the modeling process. Crystal Ball automatically generates the probability distribution for these types of effectiveness rates based on the laboratory crash data distribution and its corresponding probability risks. The laboratory crash data is treated as normally distributed. Mean and standard deviations derived from the crash tests are used to establish the normal distribution.

<u>Adjustment factors, A,</u> also come with certain variations due to automobile market fluctuations, engineering judgments, and statistical processes. Variations for these uncertainties are unknown. Thus, the adjustment factors are treated as constant.

<u>Injury redistribution factors, I</u>, are factors used to redistribute the realized benefits of higher severity injuries to lower severity injuries. These factors were derived based on many variables

such as risks of injuries and the difference in distribution of injury severity between vehicles with and without side air bags. Thus, the variation of these factors comes from the injury risk curves, crash test repeatability, and statistical process. Since uncertainties from injury risk curves and crash test repeatability already are considered in effectiveness E, these uncertainties are not considered here to eliminate the dependence between these two factors. Thus, the injury redistribution factors are treated as constants.

Injury-to-fatality ratios, R, reflect the relative economic impact of injuries compared to fatalities based on their estimated comprehensive unit costs. They were derived based on the most current 2002 crash cost assessment[148]. The crash cost assessment itself is a complex analysis with an associated degree of uncertainty. At this time, these uncertainties are also unknowns. Thus, the variation in these ratios is unknown and the analysis treats these ratios as constants.

Cumulative lifetime discount factors, D, represent the present discount factor over the vehicle's life. These factors are derived based on the agency study on vehicle miles traveled and vehicle survivability[149]. Variation of these factors comes from vehicle mileage surveys, national vehicle population, and statistical process. These uncertainties cannot be quantified at this time. Thus, the analysis treats these ratios as constants.

[148] The Economic Impact of Motor Vehicle Crashes 2000, NHTSA DOT HS 809 446, May 2002
[149] Vehicle Survivability and Travel Mileage Schedules, Technical Report, DOT HS 809 952, January 2006 (Docket No. 22223-2218)

Quantifying the Uncertainty Factors

This section establishes the appropriate probability distributions for uncertainty factors that come with appreciable variations (i.e., target population and effectiveness) and quantifies the constant values for other factors. To be consistent with the processes used in the benefit chapter, uncertainty factors are quantified separately for each of these four target populations: (1) near-side side impact, head injuries, (2) near-side side impact, chest injuries, (3) near-side side impact abdominal/pelvis injuries, and (4) far-side side impacts, occupant fatalities.

As discussed in the previous section, the analysis uses a normal distribution to describe the size of the target population. Means and standard deviations are provided here to establish the normal distributions. The standard deviation for the target population is set to be equivalent to the survey errors of the CDS. However, for a small mean target population (for example, MAIS 5 head injuries), the survey errors are relatively large. As a result, there is a significant probability that the target population would turn out to be negative during the simulation process. Obviously, it is illogical to have negative people being injured in crashes. To prevent the selection of a negative target population and to ensure the derivation of manageable variations across different population segments, standard errors are estimated first for the combined target population as a whole. Then, standard errors for each individual population segment (e.g., fatalities for 5th female) are prorated from the overall standard errors based on the size of the individual segment relative to the combined population. In order words, if SE_c represents the standard errors for the combined population P_c, the standard errors for an individual population P_c is equal to $SE_c * P_s / P_c$.

Normal distributions are also used to describe laboratory crash test data that were used to derive the effectiveness rates. Standard deviation derived directly from the crash tests are used to establish the corresponding normal distributions. However, if crash test data are too sparse to derive meaningful standard deviation, the standard deviation of the normal distribution is set to be 10 percent of the means. In other words, all crash test data fall within 30 percent of the mean test score. Basically, a normal distribution describes the possible mean crash test outcomes if various sets of vehicles were chosen to be tested. Generally, the agency carefully selects a set of vehicles that is representative of the real-world operational fleet. The mean outcome based on this set of vehicles is expected to be close to the true mean. Therefore, the agency believes that by using 10 percent of the mean as one standard deviation, the whole range of the normal distribution will be wide enough to capture the vast majority of mean test scores.

For some tests, the mean scores for vehicles tested with and without side air bags are very close. Under this circumstance, the selection process based on the established normal distributions might generate undesirable (or illogical) pair of test outcomes, i.e., an injury result with side air bags is higher than that without air bags. To eliminate the occurrence of these undesirable outcomes, each outcome is restored to its respective mean during the modeling process.

Near-Side Side Impact, Head Injuries

The head target populations were derived from CDS. Thus, the size of target head populations are treated as normally distributed. Table XII-1 lists the mean and standard deviations required for establishing the normal distributions by crash mode (vehicle-to-pole, vehicle-to-vehicle[150]) and compliance option. Generally, the target population should be segregated further by dummy size (5th percentile females and 50th percentile males) and objects the head contacted (head-to-pole/other vehicles and head-to-vehicle interior) to correspond to the effectiveness rates of side air bags which are sensitive to these two factors. However, for head injuries, the laboratory HIC injury outcomes from both dummies are very similar (see discussions below for effectiveness). Consequently, their effectiveness rates are almost identical. Therefore, the analysis combines 5th percentile females and 50th percentile males as one target population. Also, to maintain a reasonable sample size and viable variation, target populations are not segregated by objects the head contacted either. Instead, the effectiveness rates are calculated accordingly to the target population tabulation. Discussions below for effectiveness detail the process.

Table XII-1
Means and Standard Deviations for Normal Distributions
For Target Head Fatalities and MAIS 3-5 Injuries
By Crash Mode and Compliance Options*

	Fatalities (P_1)	MAIS 5 (P_2)	MAIS 4 (P_3)	MAIS 3 (P_4)
Option 1				
Vehicle-to-Pole	298	111	119	36
SD	68	25	27	8
Vehicle-to-Vehicle	651	122	249	532
SD	148	28	57	121
Option 2				
Vehicle-to-Pole	298	111	119	36
SD	68	25	27	8
Vehicle-to-Vehicle	675	122	291	600
SD	153	28	66	136
Option 3				
Vehicle-to-Pole	302	111	119	115
SD	69	25	27	26
Vehicle-to-Vehicle	675	122	291	600
SD	153	28	66	136

* Option 1: Combination head/thorax side air bags; Option 2 – Window curtain and thorax side air bags, 2 sensors; Option 3 – Window curtain and thorax side air bags, 4 sensors.
SD – Standard Deviation

[150] Represented by FMVSS No. 214, MDB test

Effectiveness is derived from two elements: laboratory crash test data and empirical injury curves. The laboratory crash test HIC results are treated as normally distributed around their means and standard deviations. Table XII-2 lists these means and standard deviations by crash mode and head contacted object. Note that probability variations for the vehicle-to-vehicle test results can not be properly developed due to limited data and are set to be 10 percent of the means. Similarly, one standard deviation for test results under the head-to-vehicle contact environment is also set to be 10 percent of mean.

Also note that although the mean vehicle-to-pole test results for 5th percentile females are slightly different from those of the 50th percentile males listed in Table XII-2, their corresponding risk probabilities are virtually identical. The effectiveness rates derived from these risk probabilities thus are identical. Therefore, only the 50th male test results are used for the analysis for both 5th percentile females and 50th percentile males.

Table XII-2
Means and Standard Deviations for HIC Vehicle Crash Test Results
For 5th females and 50th males

	Head-to-Pole/Other Vehicle		Head-to-Vehicle Interior	
Crash Mode	Without Bag	With Bag	Without Bag	With Bag
Vehicle-to-Pole				
Mean	14242	504	869	316
Standard Deviation	1969	202	87*	32*
Vehicle-To-Vehicle				
Mean	2939	458	869	316
Standard Deviation	294*	46*	87*	32*

* 10 percent of the mean

Since the same test results are applied to both dummies, the overall effectiveness for <u>each crash mode</u> basically is the weighted effectiveness of head-to-pole/other vehicles and head-to-vehicle interior. In other words, the weighted effectiveness varies depending on the distribution of objects that head had contacted. The weights are their respective proportions. Table XII-3 lists these weights for head-to-pole/other vehicles by injury severity level. The weights for head-to-vehicle interior simply are equal to 1 minus the weight for head-to-pole/other vehicle condition.

Table XII-3
Head-to-Pole/Other Vehicle Proportion
By Crash Mode and Injury Severity

Crash Mode	Fatalities	MAIS 5	MAIS 4	MAIS 3
Vehicle-to-Pole	0.767	0.704	0.693	0.595
Vehicle-to-Vehicle	0.648	0.562	0.545	0.542

The generation of probability distributions for the effectiveness rates for fatalities and individual MAIS severity level is built into the modeling process. Crystal Ball automatically generates the probability distribution for the effectiveness rates based on crash data distribution and injury risks. Figures XII-1 to XII-4 depict the probability distribution for effectiveness against fatalities and MAIS 3-5 injuries.

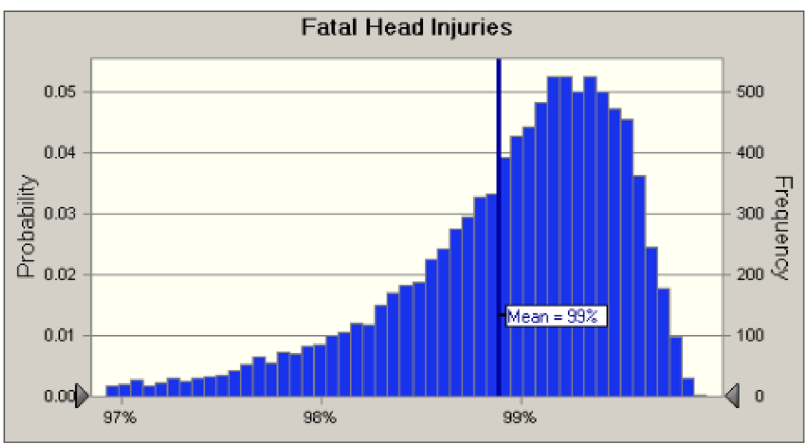

Figure XII-1
Probability Distribution of Effectiveness of Side Air Bags Against Fatal Head Injuries

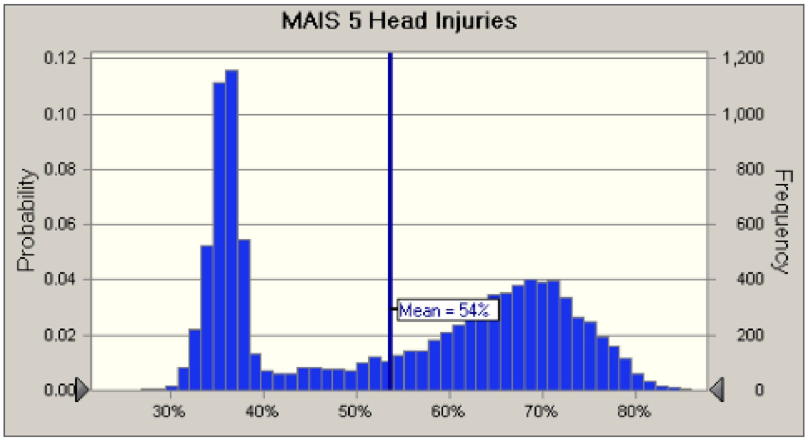

Figure XII-2
Probability Distribution of Effectiveness of Side Air Bags Against MAIS 5 Head Injuries

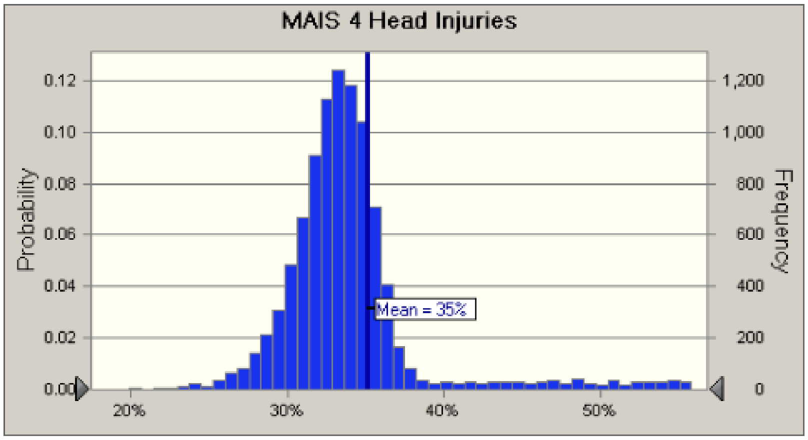

Figure XII-3
Probability Distribution of Effectiveness of Side Air Bags Against MAIS 4 Head Injuries

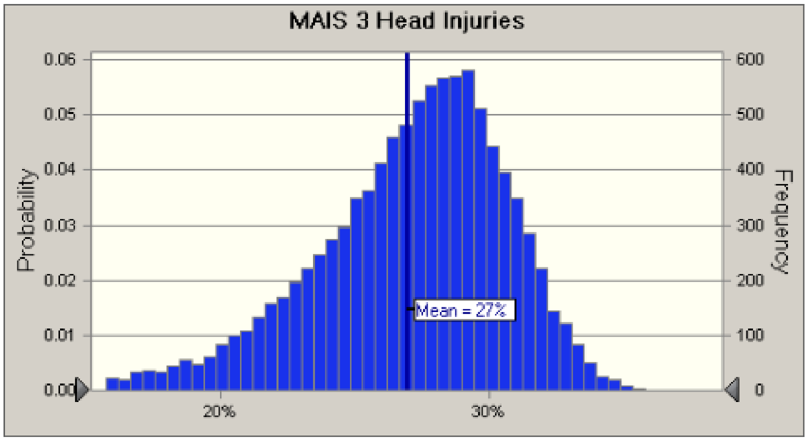

Figure XII-4
Probability Distribution of Effectiveness of Side Air Bags Against MAIS 3 Head Injuries

The simulated mean effectiveness rate against fatal head injuries is 99 percent. The simulated mean effectiveness rate for MAIS 5, MAIS 4 and MAIS 3 head injuries is 54, 35, and 27 percent, respectively. These mean effectiveness rates are high, especially for fatalities. This might be due to a narrowly selected target population (i.e., restricting to specific damage areas in vehicles, crash severity levels, and injured body regions) as described in Chapter II. This indicates that side air bags are very effective for this particular safety population (i.e., situations closely comparable to the crash pole test environments). If a wider side impact population were included, such as all injuries in side impacts regardless of injured body regions and vehicle damage areas, side air bags might not be as effective for some portions of the population, thus the overall effectiveness would be relatively smaller.

Also, as depicted in Figure XII-2, the effectiveness against MAIS 5 head injuries shows a bi-modal distribution. Basically, this phenomenon reflects that the weighted effectiveness is a combination of four different distributions. For example, for vehicle-to-pole crash mode, the effectiveness outcomes are concentrated between 20 and 30 percent with a mean of 28 percent. However, for vehicle-to-vehicle crash conditions, the effectiveness rates spread wider from 29 to 99 percent with a mean of 68 percent. Therefore, one can expect that a combination of these two distributions would be a bi-modal distribution. The disparity between these two distributions is not as acute for MAIS 3-4 injuries as for MAIS 5 injuries. Therefore, the distributions for MAIS 3-4 injuries do not show this bi-modal phenomenon.

The remaining four factors including the benefit adjustment factors (A), injury redistribution factors (I), injury-to-fatality equivalence ratios (R), and cumulative lifetime discount factors (D) are treated as constants. These constant factors are the same for each Option. Theories and methodologies that are used to derive these constants are detailed in the earlier chapters describing benefits and cost-effectiveness and Appendix B and thus are not repeated here. Table XII-4 lists the adjustment factors (A). The overall adjustment factor is the product of five different adjustment factors: projected side air bag penetration rate (a_1) in year 2011, air bag compliance rate (a_2), air bag protection area (a_3), the impact of FMVSS No. 201 (a_4), and the impact of ESC (a_5). Of these adjustment factors, air bag protection area, FMVSS No. 201, ESC factor varies depending on crash mode and injury severity.

Table XII-4
Adjustment Factors
Near-Side, Side Impact, Head Injuries

Vehicle-To-Pole

	Fatalities	MAIS 5	MAIS 4 and 3
Overall Adjustment Factor $A = (1-a_1 * a_2) * a_3 * a_4 * a_5$	0.1050	0.1141	0.1167
Projected Side Air Bag Penetration Rate (a_1)	0.93	0.93	0.93
Air Bag Compliance Rate (a_2)	0.80	0.80	0.80
Air Bag Area (a_3)	0.87	0.87	0.87
FMVSS No. 201 (a_4)	0.81	0.88	0.90
ESC (a_5)	0.59	0.59	0.59

Vehicle-To-Vehicle

	Fatalities	MAIS 5	MAIS 4 and 3
Overall Adjustment Factor $A = (1-a_1 * a_2) * a_3 * a_4 * a_5$	0.1778	0.2043	0.2118
Projected Side Air Bag Penetration Rate (a_1)	0.93	0.93	0.93
Current Air Bag Compliance Rate (a_2)	0.80	0.80	0.80
Air Bag Area (a_3)	0.93	0.93	0.93
FMVSS No. 201 (a_4)	0.805	0.925	0.959
ESC (a_5)	0.94	0.94	0.94

Table XII-5 lists the injury redistribution factors (I). Table XII-6 lists the injury-to-fatality equivalent ratios which are used to translate non-fatal injuries to fatal equivalents. Table XII-7 lists the cumulative lifetime discount factors at 3 and 7 percent discount levels. The discount factors are weighted factors of PCs and LTVs[151]. These factors are the same for all three compliance options.

Table XII-5
Injury Redistribution Factors (I)*
Near-Side, Side Impact, Head Injuries

Vehicle-To-Pole

		Fatality	MAIS 5	MAIS 4	MAIS 3
Injury Redistribution Factors For Head Injuries (I)	Fatality	0.0000	0.0019	0.0215	0.0770
	MAIS 5		0.0000	0.0215	0.0771
	MAIS 4			0.0000	0.0784
	MAIS 3				0.0000

Vehicle-To-Vehicle

		Fatality	MAIS 5	MAIS 4	MAIS 3
Injury Redistribution Factors For Head Injuries (C)	Fatality	0.0000	0.0014	0.0168	0.0649
	MAIS 5		0.0000	0.0168	0.0650
	MAIS 4			0.0000	0.0660
	MAIS 3				0.0000

* same for each discount level and compliance option

Table XII-6
Injury-To-Fatality Equivalence Ratios*

	Fatality	MAIS 5	MAIS 4	MAIS 3
Injury-To-Fatality Equivalence Ratios (R)	1.0000	0.7124	0.2153	0.0916

* same for each discount level and compliance option

Table XII-7
Cumulative Lifetime Discount Factors

	No Discount	At 3%	At 7%
Cumulative Lifetime Discount Factors (D)	1	0.8155	0.6489

[151] Lu, S., "Vehicle Survivability and Travel Mileage Schedules", NHTSA Technical Report, January 2006, DOT 809 952, Docket No. 22223-2218.

Near-Side Side Impacts, Chest Injuries

Table XII-8 lists the target chest injuries and standard deviation that are required for establishing the normal distributions to describe the variation of the target chest injuries. The target chest injuries are tabulated by crash mode (vehicle-to-pole, vehicle-to-vehicle) and compliance options. Note that the target population for Option 2 is the same as for Option 3. Also note that the target populations are not segregated further by dummy size due to limited sample size. Instead, the analysis uses the 5^{th} to 50^{th} ratio of 25:75 as weights to derive a weighted effectiveness rate of side air bags against the combined target population.

Table XII-8
Means and Standard Errors for Normal Distributions*
For Target Chest Fatalities and Injuries
By Crash Mode and Compliance Option

	Fatalities (P_1)	MAIS 5 (P_2)	MAIS 4 (P_3)	MAIS 3 (P_4)
Option 1				
Vehicle-to-Pole	46	0	204	215
SD	10	0	46	10
Vehicle-to-Vehicle	733	12	533	2,264
SD	166	3	121	514
Option 2				
Vehicle-to-Pole	46	0	204	215
SD	10	0	46	10
Vehicle-to-Vehicle	738	73	578	2,288
SD	168	17	131	520
Option 3				
Vehicle-to-Pole	46	0	204	215
SD	10	0	46	10
Vehicle-to-Vehicle	738	73	578	2,288
SD	168	17	131	520

SD: Standard Deviation

Similar to head injuries, the effectiveness rates (E) against the corresponding target chest injuries (P) were derived from injury risk curves and crash test data. The only variations considered for these effectiveness rates are from the crash test data (i.e., chest deflection measurements). The analysis treats the crash deflection results as normally distributed. Table XII-9 shows the mean and standard deviation for crash deflections by crash modes and dummy size. Note that one standard deviation is set to be 10 percent of the mean due to limited test data. As discussed earlier, the distribution basically describes the possible mean test scores if different sets of vehicles were tested. Based on the agency crash tests, chest deflection outcomes are generally low and stable, thus the agency believes that a normal distribution with one standard deviation as 10 percent of the sample mean is able to adequately describe the variations of the mean test scores. With this distribution, almost all mean test scores fall within the 30 percent of the sample mean.

Table XII-9
Means and Standard Deviations for Chest Deflection (mm) Vehicle Crash Test Results By Crash Mode and Dummy Size

	5th Percentile Female		50th Percentile Male	
Crash Mode	Without Bag	With Bag	Without Bag	With Bag
Vehicle-to-Pole	35.5	35.5	40.7	37.9
Standard Deviation*	4	4	4	4
Vehicle-To-Vehicle	19.1	17.1	37.1	28.2
Standard Deviation*	2	2	3	3

* 10 percent of the mean

Effectiveness against target chest populations (i.e., fatalities and MAIS 3-5 injuries) also is simulated by the modeling process. Figures XII-5 to XII-8 depict the probability distribution for effectiveness against fatal, MAIS 5, MAIS 4, and for MAIS 3 chest injuries, respectively. Their corresponding simulated mean effectiveness rates are 31, 32, 28, and 11 percent.

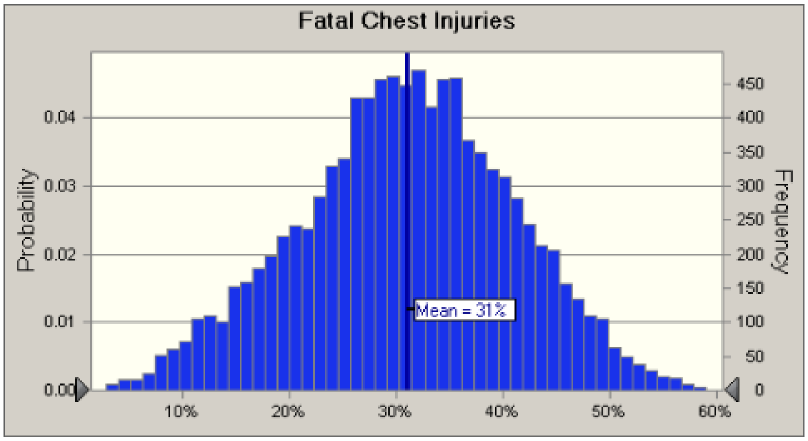

Figure XII-5
Probability Distribution of Effectiveness of Side Air Bags Against Fatal Chest Injuries

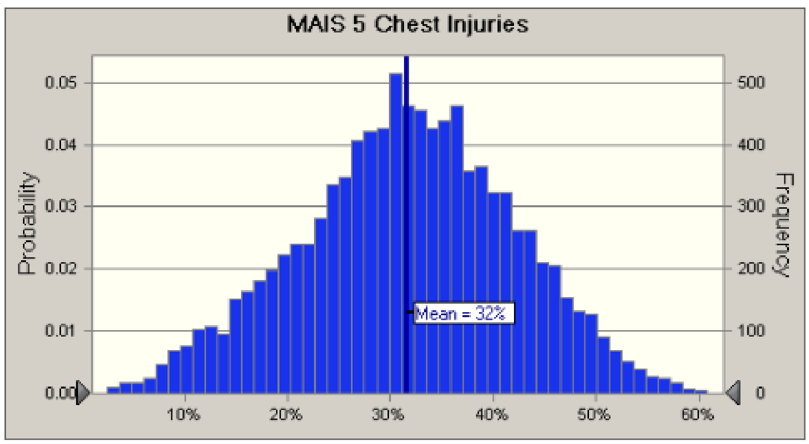

Figure XII-6
Probability Distribution of Effectiveness of Side Air Bags Against MAIS 5 Chest Injuries

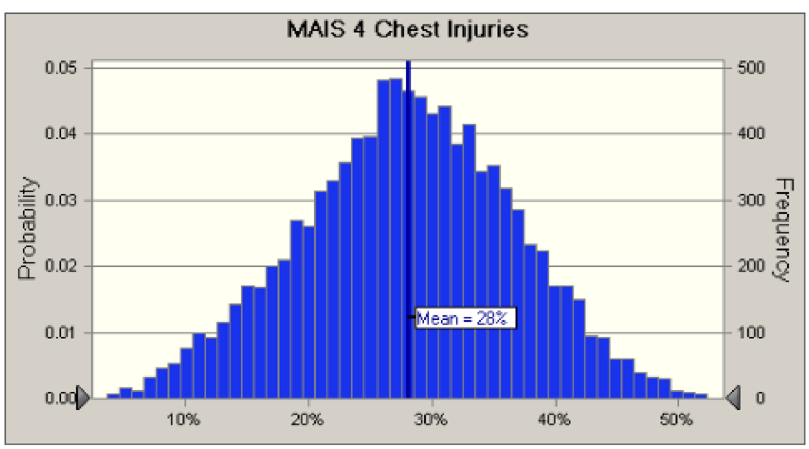

Figure XII-7
Probability Distribution of Effectiveness of Side Air Bags Against MAIS 4 Chest Injuries

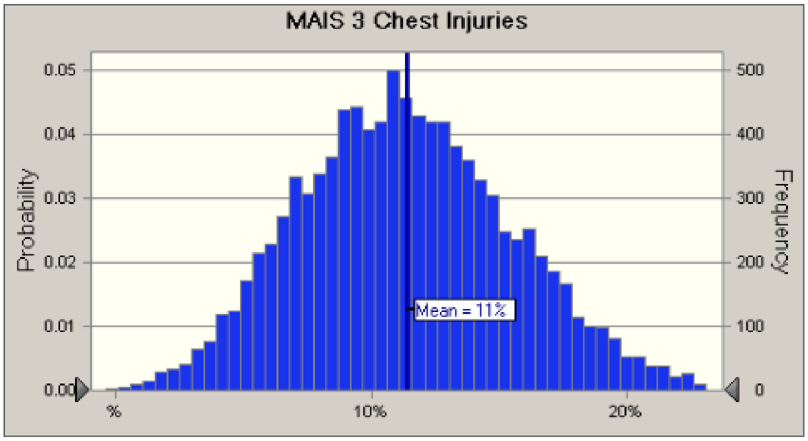

Figure XII-8
Probability Distribution of Effectiveness of Side Air Bags Against MAIS 3 Chest Injuries

Table XII-10 lists the adjustment factors for chest injuries, which is the product of five different factors. The adjustment factor for side air bag penetration rate includes an adjustment for both combination bags and torso bags. Therefore the adjustment factor is different from that for head injuries. The ESC adjustments are also different from those for head injuries due to different crash modes under which these injuries occurred. In addition, chest injuries are not expected to be impacted by FMVSS No. 201. Thus, no FMVSS No. 201 adjustment is required for chest injuries, i.e., $a_4 = 1$.

Table XII-10
Adjustment Factors
Near-Side, Side Impact, Chest Injuries

	Vehicle-To-Pole	**Vehicle-To-Vehicle**
Overall Adjustment Factor $A = (1-a_1 * a_2) * a_3 * a_4 * a_5$	0.2986	0.5085
Projected Side Air Bag Penetration Rate (a_1)	0.747	0.747
Current Air Bag Compliance Rate (a_2)	0.560	0.560
Air Bag Area (a_3)	0.870	0.930
FMVSS No. 201 (a_4)	1.000	1.000
ESC (a_5)	0.590	0.940

Table XII-11 lists the injury redistribution factors (I). Since the agency only has MAIS 4+ and MAIS 3+ chest injury curves, the injury redistribution factors can only be derived for the portions that are distributed to the MAIS 3 injuries (the last column of the table).

The remaining of two factors, R and D, are the same as those listed in Tables XII-6 and XII-7.

Table XII-11
Injury Redistribution Factors (I)*
Near-Side, Side Impact, Chest Injuries

Vehicle-To-Pole

		Fatality	MAIS 5	MAIS 4	MAIS 3
Injury Redistribution	Fatality	0.0000	0.0000	0.0000	0.4272
Factors For	MAIS 5		0.0000	0.0000	0.4272
Chest Injuries	MAIS 4			0.0000	0.4272
(I)	MAIS 3				0.0000

Vehicle-To-Vehicle

		Fatality	MAIS 5	MAIS 4	MAIS 3
Injury Redistribution	Fatality	0.0000	0.0000	0.0000	0.2502
Factors For	MAIS 5		0.0000	0.0000	0.2502
Chest Injuries	MAIS 4			0.0000	0.2502
(I)	MAIS 3				0.0000

* same for each discount level and compliance option

Near-Side Side Impact, Abdominal/Pelvis Injuries

Uncertainties surrounding the estimated abdominal/pelvis benefits cannot be quantified due to lack of data. The analysis treats the net benefits from abdominal/pelvis injuries as constants. These benefits are relatively small and would not be expected to significantly impact the overall benefits of the rule. This rule would save a net of 9 lives due to fatal abdominal/pelvis injuries and eliminate 42 MAIS 3 pelvis injuries.

Side Impact, Far-Side Occupants

The benefit estimate for far-side occupants is a FARS-centered assessment, i.e., data used to derived the benefits were exclusively from FARS. FARS is a census, not a sample, and thus does not have confidence intervals. The target population is treated as constants of 1,441, i.e., $P_1 = 1{,}441$. Of these 1,441, about 721 were occupants in PCs and 720 were in LTVs. The corresponding effectiveness (e_1) is based on the agency's study[152] which shows that head air bags and torso bags combined are 24 percent effective against unbelted fatalities in far-side side-impacts (far-side occupants) for PCs and no effect for LTVs. The 90 percent confidence bounds for the mean effectiveness of 24 percent are estimated to be 4 to 42 percent. One standard error is about 12 percent and is used as the proxy for standard deviation. That is, the analysis assumes that the effectiveness for PCs is normally distributed with mean of 24 percent and a standard deviation of 12 percent. This effectiveness is applied only to occupants in PCs to derive far-side benefits. In addition, the analysis assumes that the combination bags (i.e., Options 1) would not be effective in reducing far-side occupant fatalities. Thus, Only Options 2 and 3 would accrue far-side benefits.

The adjustment factor (A) for far-side occupants is also treated as constant and is equal to 0.2223, which accounts for projected side air bag market penetration rate (a_1=0.9343), air bag compliance rate (a_2=0.80), and the impact of ESC (a_4=0.88).

The derived benefits are treated as the net benefits, thus there is no redistribution of these lives saved to lower injury severity level injuries. The remaining factors, injury-to-fatality

[152] An Evaluation of Side Impact Protection, FMVSS 214 TTI(d) Improvements for Passenger Cars, Preliminary Analysis of Side Air Bags for Cars and LTVs, NHTSA Technical Report, DOT HS 809 xxx, to be published

equivalency ratios and cumulative lifetime factors are the same as those discussed in the head injury section (Tables XII-6 and XII-7).

The above sections discuss the four components of the FE models. FE is the basic benefit measurement for estimating cost-effectiveness. For estimating the net benefits, FE is translated into dollars. If M denotes the cost per fatality, the benefit in the net benefit calculation is equal to M*FEs. M clearly is another uncertainty factor for net benefits. Recent meta-analysis of the wage-risk value of statistical life (VSL) shows that an individual's willingness-to-pay (WTP) for reduction in premature fatalities is from $1 million to $10 million[153]. Thus, the agency uses this as the range for M and assumes the value of M is normally distributed with its mean equal to $5.5 million. This value of $5.5 million represents a central value consistent with a range of values from $1 to $10 million.

[153] a: Mrozek, J.R. and L.O. Taylor, What determines the value of a life? A Meta Analysis, Journal of Policy Analysis and Management 21 (2), pp. 253-270.

b: Viscusi , W. K., The Value of Life: Estimates with Risks by Occupation and Industry, Economic Inquiry, Oxford University Press, vol. 42(1), pages 29-48, January, 2004.

c: Viscusi, W. K. & Aldy, J.E., The Value of a Statistical Life: A Critical Review of Market Estimates Through Out the World, Journal of Risk and Uncertainty, Kluwer Academic Publishers, vol. 27(1), pages 5-76, August, 2003.

A.2 Total Cost Model

The total cost (TC) is the product of the cost per vehicle (C) and the total number of vehicles (V). Therefore, C and V are two uncertainty factors for the cost model.

Cost per vehicle, C, is a concern. The sources of cost uncertainties arise from, but are not limited to, maturity of the technologies/countermeasures and potential fluctuation in labor and material costs (e.g., due to economics from production volume). According to professional judgments of NHTSA cost analysts and contractors, the cost will fall within 10 percent of the point estimate shown in the cost chapter. Any cost in this range would have equal chance to be the true cost. Thus, the analysis assumes the cost is uniformly distributed. The uniform distribution for C would be established by two parameters: maximum (C_{max}) and minimum (C_{min}) costs, i.e.,

$$
\begin{aligned}
C(x) &= \frac{1}{C_{Max} - C_{Min}}, C_{min} \le x \le C_{max} \\
&= 0, \text{otherwise}
\end{aligned}
$$

C_{max} and C_{min} varied depending on the implementation options. Table XII-12 lists the average incremental costs for the three options. These costs represent the investments paid now for future benefits. Therefore, there is no need to discount these costs.

TABLE XII-12
COST PARAMETERS FOR UNIFORM DISTRIBUTION BY THREE OPTIONS

	Option 1 Combination Head and Thorax Bags	Option 2 Window Curtain and Thorax Side Air Bags 2 Sensors	Option 3 Window Curtain and Thorax Side Air Bags 4 Sensors
The Most Likely Cost (point estimate)	\$25.0	\$33.0	\$66.0
Minimum Cost (C_{min})	\$22.0	\$30.0	\$59.0
Maximum Cost (C_{max})	\$28.0	\$36.0	\$73.0

<u>Number of Vehicles, V</u>, is the last uncertainty factor for the total cost model. Although vehicle sales have gradually increased over time, they are subject to annual variation due to changes in economic conditions, which are difficult to predict. Thus, the number of vehicles (V) is treated as a constant of 17 million. Of these, 8 million are passenger cars and 9 million are light trucks, vans, and sport utility vehicles.

<u>A.3 Cost-Effectiveness Model and Net Benefit Model</u>

After the fatal equivalent (FEs) and the total cost models were established, the cost-effectiveness model (CE) is calculated as the ratio of total costs (TC) to fatal equivalents. It has the format: CE = TC/FEs. The net benefits (NB) has the format: NB = M*FEs – TC, where M is the cost per fatality.

B. Simulation Results

The Monte Carlo simulation first randomly selects a value for each of the significant factors based on their probability distributions. Then, the selected values are fed into the model to forecast the results. Each process is a trial. The simulation repeats the process until a pre-defined accuracy has been accomplished. Since Crystal Ball is a spreadsheet based simulation software, the simulation model actually is a step-wise process, i.e., the simulation estimates gross benefits, the net benefits (after redistribution of gross benefits through the injury redistribution process), fatal equivalents, cost-effectiveness, and net benefits. Therefore, each of these forecasted results has certainty bounds. This uncertainty analysis conducted a total of 10,000 trials before the forecasted mean results reached 99 percent precision. Even if the later criterion was reached first, the trial numbers generally are very close to 10,000. These criteria were chosen to ensure the simulation errors ($\approx \frac{1}{10{,}000}$) would be very close to 0. Therefore, the results would truly reflect the probabilistic nature of the uncertainty factors.

Table XII-13 summarizes the simulated results after about 10,000 trials. Based on the simulated results as shown in Table XII-13, <u>at no discount level</u>, the rule would save 236 to 443 equivalent lives for Option 1; 283 – 503 for Option 2; and 283 – 504 for Option 3 all with a 90 percent certainty. All three options would produce a cost per equivalent fatality of no more than $5.5 million with an extremely high certainty level. If $3.7 million is used as the threshold for cost-effectiveness, all three options would still satisfy this threshold with more than a 90 percent certainty.

<u>Undiscounted</u>, the estimated mean net benefits of the rule would range from $1.0 to $1.6 billion (B) depending on the compliance technology options. Generally, the higher range of net benefits

would be achieved by implementing Option 2 and the lower range by Options 3. All three compliance options would produce a positive net benefit with over 95 percent certainty.

At a 3 percent discount rate, the rule would save 192 - 361 equivalent lives for Option 1; 231 – 410 for Option 2; and 231 – 411 for Option 3. All three options would produce a cost per equivalent fatality of no more than $5.5 million with an extremely high certainty level (over 98 percent). If $3.7 million is the threshold, Options 1 and 2 would meet the threshold with a 100 percent certainty and Option 3 with a 59 percent. At this discount rate, the estimated mean net benefits of the rule are: $1.1 B for Option 1; $1.2 B for Option 2; and $0.6 B for Option 3. All three compliance options of the rule would produce a positive net benefit with a high degree of certainty (over 88 percent).

At a 7 percent discount rate, the rule would save 153 – 287 equivalent lives for Option 1; 184 – 326 for Option 2; and 184 – 327 for Option 3. Options 1 and 2 would produce a cost per equivalent fatality of no more than $5.5 million with a 100 percent certainty. For Option 3 the uncertainty level is 86 percent. If $3.7 million is the threshold, Options 1 and 2 would still meet it with an extremely high certainty level. However, Option 3 would meet this threshold with a merely 14 percent certainty. Finally, at this discount rate, the rule would still produce positive mean net benefits ranging from $0.3 to $0.8 B. All three options would be most likely to produce positive net benefits than negative benefits. Options 1 and 2 would produce a positive net benefit with more than 98 percent certainty. The certainty level for Options 3 is 71 percent.

Summary

The rule is generally favorable. Of the three implementation options, Options 1 and 2 are more favorable than Options 3 based on cost-effectiveness, net benefits, and associated certainty levels. With the higher discount rate of 7 percent, the rule would produce a cost per equivalent fatality of no more than $5.5 million with a 100 percent certainty for Options 1 and 2, and a 86 percent certainty for Option 3. If the threshold is $3.7 million, Options 1 and 2 would still meet the threshold with an extremely high level of certainty. Option 3 would not be cost-effective. Nevertheless, this rule would be more likely to produce positive mean net benefits and positive overall net benefits than negative results: over 98 percent certainty for Options 1 and 2 and 71 percent for Option 3.

The point estimates of benefits in Chapter VII are very close to the mean simulated results. The fact that they are not identical is partially due to rounding, and partially to the method used to generate effectiveness in this analysis. This analysis used Crystal Ball to naturally fit the laboratory vehicle crash tests and injury curve data. With expected statistical errors resulting from the data fitting process, the estimated means of the effectiveness based on this process might be slightly different from the point estimates of effectiveness used in Chapter VII.

TABLE XII-13
Simulated Cost-Effectiveness and Net Benefits

No Discounting	Option 1	Option 2	Option 3
Mean Total Cost*	$429 M	$560 M	$1,124 M
90% Certainty for Total Costs*	$383 – $468 M	$505 – $617 M	$1,010 – $1,234 M
Mean Equivalent Lives Saved	335	388	389
90% Certainty for Equivalent Lives Saved	236 – 443	283 – 503	283 – 504
Mean CE	$1.3 M	$1.5 M	$3.0 M
Certainty that CE <= $3.7 M	100%	100%	90%
Certainty that CE <= $5.5 M	100%	100%	100%
Mean Net Benefits	$1,416 M	$1,575 M	$1,018 M
90% Certainty for Net Benefits	$505 - $2,472 M	$547 - $2,785 M	-$22 – $2,218 M
Certainty that Net Benefits > $0	100%	100%	95%
At 3% Discount Rate			
Mean Equivalent Lives Saved (present value)	273	317	317
90% Certainty for Equivalent Lives Saved (present value)	192 – 361	231 – 410	231 – 411
Mean CE	$1.6 M	$1.8 M	$3.6 M
Certainty that CE <= $3.7 M	100%	100%	59%
Certainty that CE <= $5.5 M	100%	100%	98%
Mean Net Benefits	$1,076 M	$1,181 M	$623 M
90% Certainty for Net Benefits	$333 - $1,937 M	$343 - $2,169 M	-$226 – $1,607 M
Certainty that Net Benefits > $0	100%	99%	88%
At 7% Discount Rate			
Mean Equivalent Lives Saved (present value)	217	252	253
90% Certainty for Equivalent Lives Saved (present value)	153 – 287	184 – 326	184 – 327
Mean CE	$2.0 M	$2.3 M	$4.6 M
Certainty that CE <= $3.7 M	100%	99%	14%
Certainty that CE <= $5.5 M	100%	100%	86%
Mean Net Benefits	$770 M	$825 M	$267 M
90% Certainty for Net Benefits	$178 - $1,457 M	$160 - $1,611 M	-$409 to $1,053 M
Certainty that Net Benefits > $0	99%	98%	71%

M: million; CE: cost per fatal equivalent
* same for all discount rates

Appendix A.

The side impact air bags sales volume

The side impact air bags sales volume was estimated based on Buying a Safer Car, Wards sales data and manufacturer's reported sales. For the 1999 – 2004, data from Buying Safety Car and Wards are used, and for the 2005, Buying Safety Car and the manufacturer's reported sales were used, as shown below:

Passenger Cars:								
	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Total**
Thorax only	1,076,826	1,350,624	1,038,412	1,263,040	698,534	551178.44	793356	6,771,970
AC+Th	98,241	126,436	649,990	796,903	1,323,971	1750521.3	1996106.8	6,742,169
Combo	167,716	638,806	797,054	725,750	723,632	703656.49	979318.71	4,735,934
AC only	0	0	38,328	123,379	85,858	133562.25	96657.299	477,786
ITS+Th	122,973	138,834	159,154	170,519	200,449	209770	181850	1,183,549
Total	1,465,756	2,254,699	2,682,938	3,079,591	3,032,445	3,348,689	4,047,289	19911407

Distribution of Head and Thorax Air Bags (up to 2005 estimated sales)								
	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Average**
Head Protection Only	0.00%	0.00%	0.46%	1.49%	1.04%	1.77%	1.21%	0.95%
Thorax Protection Only	12.45%	15.04%	12.50%	15.23%	8.42%	7.31%	9.94%	13.53%
Head and Thorax Protection	4.50%	10.07%	19.33%	20.41%	27.11%	35.31%	39.55%	25.29%
Total	16.95%	25.11%	32.29%	37.13%	36.56%	44.38%	50.70%	39.77%

Light Trucks:								
	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Total**
Thorax only	8,526	372,761	412,754	1,214,731	1,326,565	1067735.5	931661	5,334,733
AC+Th	0	0	14,983	193,480	279,966	844747.58	1764284.8	3,097,461
Combo	84,171	144,366	481,656	524,397	614,924	106800	319118.44	2,275,432
AC only	0	0	0	46,701	312,947	482641.92	554493.01	1,396,783
ITS+Th	0	16,841	39,741	43,207	52,198	150100	46800	348,887
Total	92,697	533,968	949,134	2,022,515	2,586,599	2,652,025	3,616,357	12453296

Distribution of Head and Thorax Air Bags (up to 2005 estimated sales)								
	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**Average**
Head Protection Only	0.00%	0.00%	0.00%	0.52%	3.23%	5.06%	5.68%	2.63%
Thorax Protection Only	0.11%	4.34%	4.99%	13.60%	13.69%	11.19%	9.54%	10.05%
Head and Thorax Protection	1.04%	1.88%	6.49%	8.52%	9.77%	11.55%	21.80%	10.78%
Total	1.15%	6.22%	11.49%	22.64%	26.69%	27.80%	37.02%	23.46%

Absolute Values for Passenger Cars and Light Trucks								
	1999	2000	2001	2002	2003	2004	2005	Total
Thorax only	1,085,352	1,723,385	1,451,166	2,477,771	2,025,099	1,618,914	1725017	12,106,703
AC+Th	98,241	126,436	664,973	990,382	1,603,937	2,595,269	3760391.6	9,839,630
Combo	251,887	783,171	1,278,710	1,250,147	1,338,557	810,456	1298437.1	7,011,365
AC only	0	0	38,328	170,081	398,805	616,204	651150.31	1,874,568
ITS+Th	122,973	155,675	198,895	213,726	252,647	359,870	228650	1,532,436
Total	1,558,453	2,788,667	3,632,072	5,102,107	5,619,044	6,000,713	7,663,646	32364703

Distribution of Head and Thorax Air Bags (up to 2005 estimated sales)								
	1999	2000	2001	2002	2003	2004	2005	Average
Head Protection Only	0.00%	0.00%	0.23%	0.99%	2.22%	3.61%	3.67%	1.55%
Thorax Protection Only	6.49%	9.81%	8.76%	14.38%	11.26%	9.48%	9.72%	10.01%
Head and Thorax Protection	2.83%	6.06%	12.93%	14.25%	17.76%	22.04%	29.78%	15.21%
Total	9.32%	15.88%	21.92%	29.62%	31.24%	35.12%	43.17%	26.77%

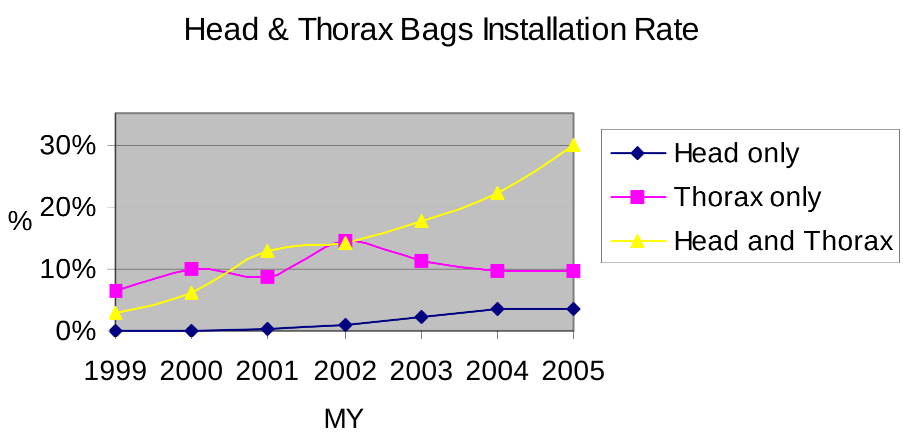

Figure A-1. Head and Thorax Bag Distribution By Bag Type and Model Year

MY 2011 Estimated Side Air Bag Sales*

	Vehicle Sales	% of Vehicle Sales
Thorax only	78,823	0.47%
Curtain only	3,217,511	19.19%
Curtain + Thorax	11,295,538	67.38%
Combo	884,551	5.28%
Thorax + Other head bags	263,770	1.57%
Total Vehicle Sales	16,762,996	100%
Total Equipped with bag	15,740,193	93.90%
ANY Thorax bag	12,522,682	74.70%
ANY Head bag	15,661,370	93.43%
Thorax bag only	78,823	0.47%
Head bag only	3,217,511	19.19%

* Six vehicle manufacturers responded confidentially to a NHTSA request for planned side air bag installations and projected sales through model year 2011. The estimated sales are based on the confidential data.

Appendix B.

Head and Side Air Bag Hypothetical Case Study

As discussed in this chapter, a point estimate was used to derive the benefits. The point estimate was based on characteristics of air bags at a single vehicle delta-V of 20 mph. To further investigate head injuries in different crash environments, several hypothetical side crash cases were examined.

1. Head impacts to pole/tree

Baseline HIC: As part of the pole impact research program, the agency performed a series of pole tests with the ES-2re 50th percentile male test dummy. The pole test results are shown in Table B-1 below:

Table B-1
Vehicle Sled Pole Test Data
ES-2re with the 201 seating procedure
Baseline, without Air Bags

	HIC at a given delta-V (mph)	
Vehicle Tested	18	20
1999 Nissan Maxima	---	11,983
1999 Nissan Maxima	---	15,591
1999 Nissan Maxima	4,728	
2001 Saturn	---	15,152
2001 Saturn	9,004	---
Avg. HIC:	6,866	14,242

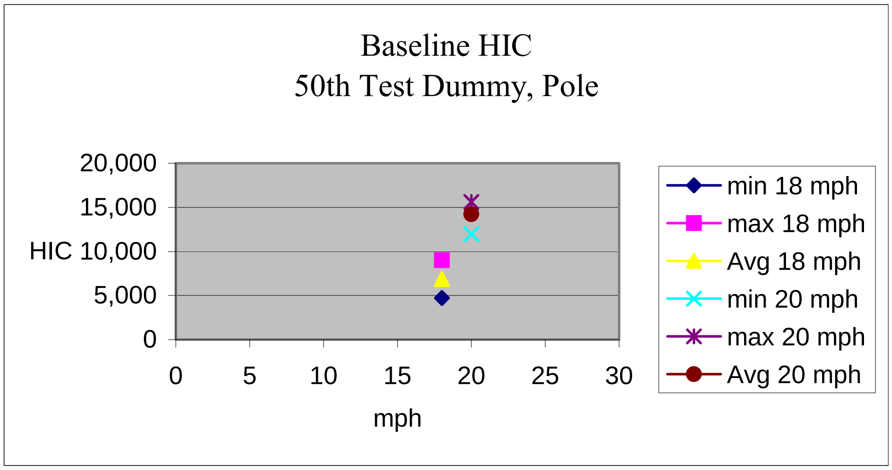

Figure B-1. Baseline HIC, Head-to-pole, 50th

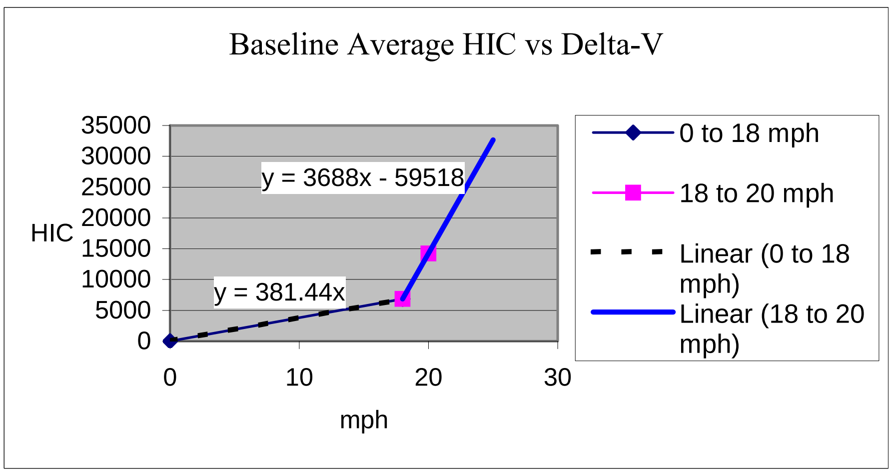

Figure B-2. Baseline HIC with Trend line

Based on the linear approximation, HIC scores with respect to vehicle delta-V are estimated, as shown below:

Table B-2
Estimated Baseline HIC Scores
With respect to Vehicle Delta-V
50th Test Dummy, Head-to-Pole/Tree Impact

Delta-V (mph)	12	16.78	18	19	20	23	25
HIC	4,577	6,401	6,866	10,554	14,242	25,306	32,682

HIC with Deployed Air Bag: A series of pole tests were performed with the ES-2re, 50th percentile male test dummy. The 214-seating procedure was used for the test dummy. The pole test results are shown in Table B-3:

Table B-3
Vehicle Sled Pole Test Data, ES-2re, with Deployed Air Bag
With 214 Seating Procedure

Vehicle	Head Bag	HIC at a given delta-V 18 mph	20 mph
1999 Volvo S80	AC+Th	---	329
2000 Saab 9-5	Combo	---	171
2004 Honda Accord	AC+Th	---	446
2004 Toyota Camry	AC+Th	---	405
2005 Toyota Corolla	AC+Th	---	473
2005 (&1/2) VW Jetta	AC+Th	---	652
2005 Beetle Convertible	Combo	---	315
2005 Saab 9-3 Convertible	Combo	---	254
2005 Ford Five Hundred	AC+Th	---	422
2004 Toyota Sienna	AC+Th	---	667
2005 Honda CRV	AC+Th	---	639
2005 Chevy Colorado	AC	---	784
2005 Ford Expedition	AC	---	689
2001 Saturn Ion	AC	---	806
Avg			504

Table B-4
Vehicle Sled Pole Test Data, ES-2re, with Deployed Air Bag
With 201 Seating Procedure

Vehicle	Head Bag	HIC at a given delta-V 18 mph	20 mph
2000 Saab	Combo	---	243
2000 Saab	Combo	114	---
1999 Volvo S80	AC+Th	---	465
1999 Volvo S80	AC+Th	244	---
1999 Nissan Maxima	Combo	130	---
2001 Saturn	AC	---	670
2001 Saturn	AC	435	---
2002 Ford Explorer	AC	208	---
1999 Mercury Cougar	Combo	313	---
1999 Ford Windstar	Combo	164	---
2002 Ford Explorer	AC		629
Avg		230	502

Table B-5
Overall Deployed Bag Average HIC
And Bag Type

Impact Speed (vehicle delta-V)	18 mph	20 mph
Overall Deployed Bag HIC Average	230	503
AC	296	559
Combo	180	246

In addition to the pole tests, the pendulum tests performed by Volvo & Autoliv were also examined. (See "The inflatable curtain (IC) – A new head protection system in side impacts." 16th International Technical Conference on the Enhanced Safety of Vehicles, Paper Number 98-S8-W-29. http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/esv/esv16/98s8w29.pdf). In the pendulum test, a head form with a weight of 6.8 kg and diameter of 165 mm was attached a pendulum. The head form moves in a pendulum motion and hits the head air bag (air curtain) inflated with 150 kPa. Behind the head air bag, a stiff un-deformable block was placed which simulates external rigid contact surfaces. In its reports, Volvo determined that 7 m/s corresponds to a pole test at 32 km/h, (approx. 20 mph)[154]. The pendulum test results are duplicated in Figure B-3.

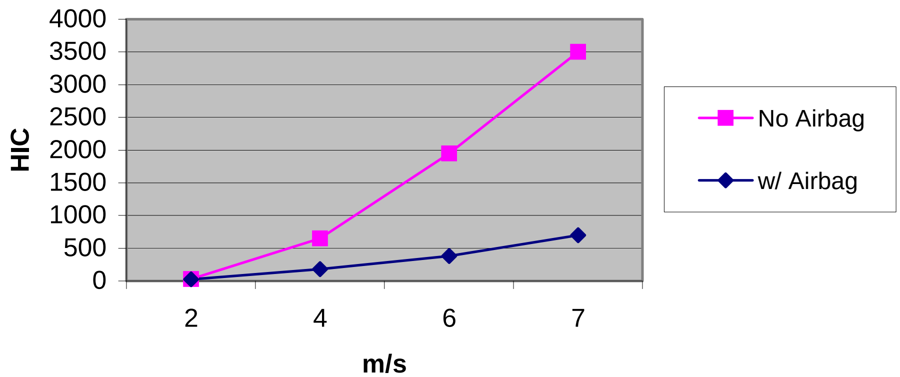

Figure B-3. Pendulum Test: HIC vs. Impact Velocity (with 55 mm cell thickness, Air Curtain)

[154] Note that the pendulum speed is regarded as occupant delta-V, whereas pole test speed is regarded as vehicle delta-V. It is suspected that the impact speed (i.e., 7 m/s, 15.66 mph) was converted to vehicle delta-V with a conversion factor of 1.3, such that 15.66 mph x 1.3 = 20 mph. The conversion factor (of 1.3) was also used in FEA, FMVSS No. 201.

In the test, only horizontal velocity component was used for the HIC measurement. The report states that the air bag started to bottom out into the fixture block at 7 m/s, at a pressure of about 150 kPa. (Note that when air bag pressure increases, more kinetic energy is required for the air bag to bottom out; however, with the increased air bag pressure (harder air bags), HIC values would also increase.) The report concludes that the pressure level 160 to 220 kPa is favorable to cover pendulum impact velocity up to 15 mph (i.e., a vehicle delta-V of 20 mph). The HIC scores measured from the Volvo pendulum test are shown in Table B-6.

Table B-6
Volvo Pendulum HIC Results

Pendulum (mph)	Vehicle Delta-V (mph)	HIC
0	0	0
9	12	200
13	17	450
16	20	700

The HIC test results from the pole and pendulum tests are plotted in Figure B-4.

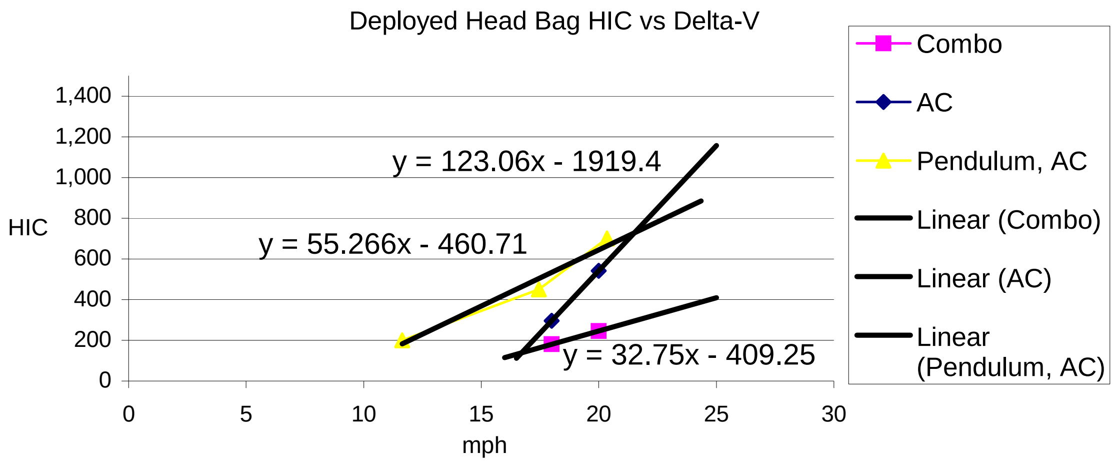

Figure B-4. HIC results from Pole and Pendulum Tests

The HIC varies with the 2.5 power of the head acceleration, and the impact energy (kinetic energy associated with the mass) varies with the square power of the impact speed. Thus, we suspect that the variation of the HIC with respect to the impact speed would not be linear. Consequently, the linear approximation used in the HIC estimate would result in lower HIC scores for vehicle delta-V's that are outside of the range and higher HIC scores for delta-V's within the range. However, the difference would be small for delta-V's close to the actual impact test speeds.

For each bag and test type, the actual and estimated HIC scores are shown below:

Table B-7
HIC Scores vs. Vehicle Delta-V, 12 mph – 25 mph
Combo, Vehicle Curtain, and Pendulum Curtain

Delta-V (mph)	12	16.78	18	19	20	23	25
Combo bag	N/A	140	180	213	246	344	410
AC	N/A	135	296	428	560	955	1,219
Pendulum, AC	202	467	534	589	645	810	921
Average HIC	202	247	337	410	483	703	850

The results in Table B-7 show that an average HIC of 247 would be measured from the systems at a vehicle delta-V of 16.78 mph. It appears that the estimated HIC 247 is a reasonable proxy when compared to the actual ITS HIC score measured at the same impact speed (of 16.78 mph). In the ITS test results (NHTSA-1997-1762-017,DMS Web, #1762), a HIC of 230 was measured at a vehicle delta-V of 16.78 mph. When only the combo and curtain air bags are considered, the estimated HIC scores would be 312 at a delta-V of 19 mph. According the Preliminary Regulatory Evaluation of FMVSS No. 201 (April 19970, Docket number 92-028 Notice 8), a HIC score of 331 was measured with a deployed ITS in a vehicle delta-V of 19 mph (i.e., 18.64 mph) in a pole sled test. When compared to the actual ITS test data, it appears that the derived

HIC profile would reasonably well predict HIC scores that would be measured with deployed air bags in heads-to-pole crashes in side crashes. The derived HIC profile (showing only 12 – 25 mph range) is shown in Figure B-5.

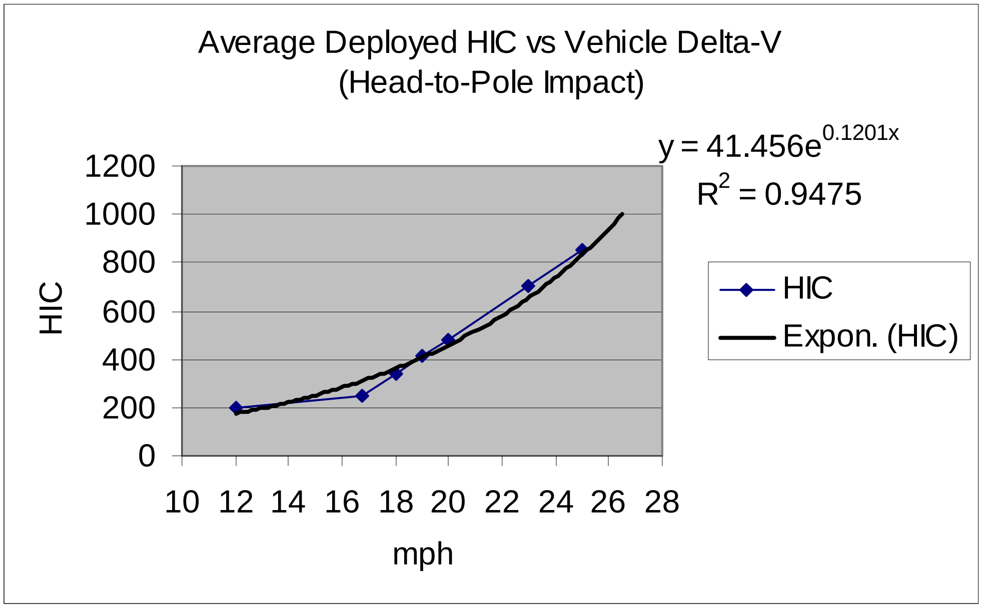

Figure B-5. Estimated HIC profile with Deployed Air Bag in Head-to-Pole Impacts

2. Head impacts to vehicle interior components

<u>Baseline HIC</u>: In the Preliminary Regulatory Evaluation of FMVSS No. 201, (April 1997, Docket #: 92-028 Notice 8), the ITS HPS system was evaluated by a series of sled tests with a Eurosid instrumented test dummy. The dummy's head was impacted to the vehicle B pillar with and without the deployed head air bag. The head-to-B pillar test results are shown in Table B-8.

Table B-8
HIC Scores In Head-to-B pillar Impacts

Speed (km/h)	Speed (mph)	Occupant Delta-V (estimated)	Head Contact	Base HIC	ITS HIC	Effect.
27	16.78	12.84	B-Pillar	700	270	61.43%
51	31.69	24.24	B-Pillar	1,900	560	70.53%

The results are further analyzed for the baseline HIC score, as shown below:

Table B-9
Baseline HIC Scores In Head-to-B pillar Impacts

Speed (km/h)	Speed (mph)	Occupant Delta-V	Head Contact	Dummy HIC
27	16.78	12.84	B-Pillar	700
51	31.69	24.24	B-Pillar	1,900

As part of the FMVSS No. 201 Rulemaking, the agency performed a series of head-form tests to determine effectiveness of the potential countermeasure (padding) in providing head protection. Since crash mode, vehicle structure, weight of the torso, air bag thickness, air bag operation pressure and other factors would affect the load, a HIC measurement made with a (full) test dummy would be different from a HIC measurement made with the head-form at the same impact speed. To reflect these factors, the head-form HIC measurements were converted to (full) dummy HIC scores. In Final Economic Assessment (FEA), FMVSS No. 201, June 1995, a full dummy HIC conversion factor was developed based on the FMVSS No. 201 head-form test results, as shown below:

$$\text{Full Dummy HIC} = 0.75446\ (\text{FMH HIC}) + 166.4$$

Since impact velocities measured with the head-form would be considered as “occupant delta-V,” the corresponding vehicle delta-V’s were derived based on a conversion factor of 1.3. (Note that the conversion factor is based on studies done by Monk, Gabler and Sullivan, 1987. Previously, the factor was used in the FEA FMVSS No. 201 to convert vehicle delta-V’s to occupant delta-V’s.) The baseline HIC scores measured at B pillar are shown in Table B-10

Table B-10
HIC Scores Result from 201 Head Form Test
Head Contact at B Pillar, In 201 FEA
(NHTSA Padded)

Vehicle	FMH Speed (mph)	Vehicle Delta-V	Occupant Delta-V	Dummy HIC
Honda Civic	20	26	20	982
VW Golf	20	26	20	1,367
VW Golf	15	20	15	858
Toyota Camry	20	26	20	1,559
Toyota Camry	15	20	15	628
Ford Taurus	20	26	20	1,875
Ford Taurus	15	20	15	879
Grand Marquis	15	20	15	906
Ford Taurus	20	26	20	1,241
Honda Civic	20	26	20	799
Toyota Camry	20	26	20	1,091
Chevrolet Caprice	15	20	15	756
Chevrolet Caprice	15	20	15	686

Avg HIC at a vehicle delta-V of 26 mph (std dev.):	1,273 (364.4)
Avg HIC at a vehicle delta-V of 20 mph (std dev.):	786 (113.2)

In addition, HIC scores result from the FMVSS No. 201 head form compliance tests were also analyzed. The results from the 2003 model year vehicles are shown in Table B-11.

Table B-11
Head Form HIC Results
2001 Model Year Vehicles
15 mph Occupant Delta-V
(20 mph Vehicle Delta-V)

Vehicle: 2003 Model	FMH HIC	Dummy HIC
Dodge Durango	595	
	613	
	510	598
Ford Ranger	467	
	563	
	433	534

Table B-11 (continued)

Honda Accord	719	709
Honda Pilot	598	
	563	
	598	609
Hyundai Elantra	783	
	741	741
Jeep Liberty	661	
	604	
	682	656
Pontiac Vibe	623	
	551	609
PT Cruiser	718	
	637	
	885	730
Saturn Ion	569	
	607	
	802	664
Subaru Forester	458	
	614	
	505	563
Suzuki Grand Vitara	467	
	423	502
	611	
	555	
Toyota Corolla	496	584
Average HIC at a vehicle Delta-V of 20 mph		625

The head-form HIC scores measured at a 15 mph impact speed show that the 2003 model year vehicles have approximately 20% lower HIC scores when compared to the vehicles used for the FMVSS No.201 rulemaking. The HIC results from the three tests (ITS, NHTSA 201 Rulemaking, and NHTSA 201 Compliance) are plotted with trend lines below:

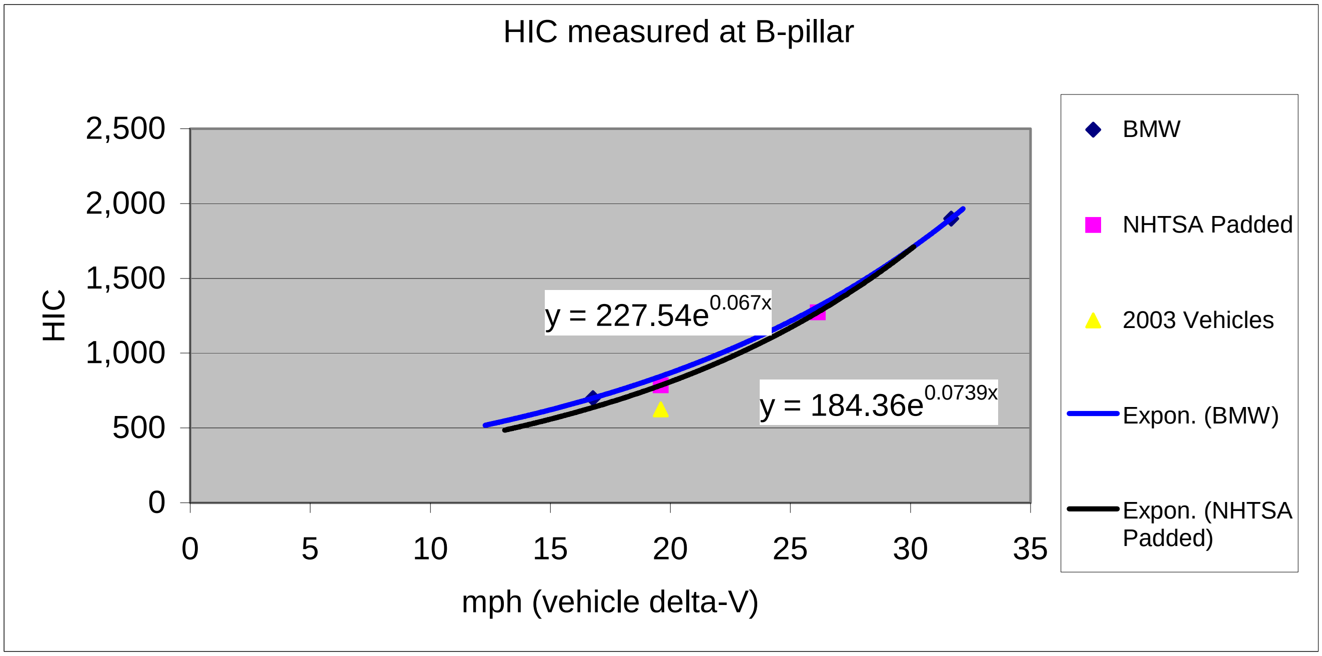

Figure B-6. Estimated Baseline HIC Scores at B Pillar

We note that although the HIC scores from the 2003 model year vehicles would represent the more modern vehicles in head-to-B Pillar impact, the HIC scores were measured only at a single impact speed.

In the 20-Preliminary Regulatory Economic (PRE) analysis, the agency discussed the structural theory regarding HIC. According to the theory, the acceleration response of a simple linear elastic system is a function of its initial velocity if the system's initial displacement equals to zero. Further, it said, "This system model simulates the head-to-pillar impacts very well." For example, according to the theory, there is a factor that estimates a certain delta-V equivalent of a HIC at existing delta-V. For example, the HIC at 18 mph could be derived from the HIC at 15 mph with a factor of 1.577. For the baseline HIC (for head-to-B pillar), we compared the HIC estimate based on the theory to HIC estimate based on an extrapolation of the ITS test results. The HIC comparison is shown in Table B-12.

Table B-12
Comparison of HIC Between "Structure Theory" and "ITS HIC Extrapolation

Vehicle Delta-V (mph)	Theory based on 16.78 mph HIC	Theory based on 31.69 mph HIC	HIC based on the ITS	Actual HIC
12	303	168	508	
14	445	246	581	
16	621	344	665	
16.78	700	388	700	700
18	834	462	760	
20	1,086	601	869	
22	1,378	763	994	
24	1,713	948	1,136	
26	2,092	1,158	1,299	
28	2,518	1,394	1,485	
30	2,992	1,657	1,698	
31.69	3,431	1,900	1,902	1,900

The results in Table B-12 show that the HIC estimate based on 16.78 mph would overestimate HIC at impact speeds higher than 16.78 mph. On the other hand, the HIC estimate based on 31.69 mph would underestimate HIC scores lower that 31.69 mph. Accordingly, it is determined that the HIC estimate based on the ITS HIC scores would result in a better estimate when compare to the other methods. The estimated HIC scores based on the ITS HIC extrapolation are shown in Table B-13 and Figure B-7.

Table B-13
Estimated HIC Score, Head Impacts with Vehicle Interior Components

Vehicle Delta-V (mph)	Baseline HIC
12	508
13	544
14	581
15	622
16	665
17	711
18	760
19	813
20	869
21	929
22	994
23	1,062
24	1,136
25	1,215

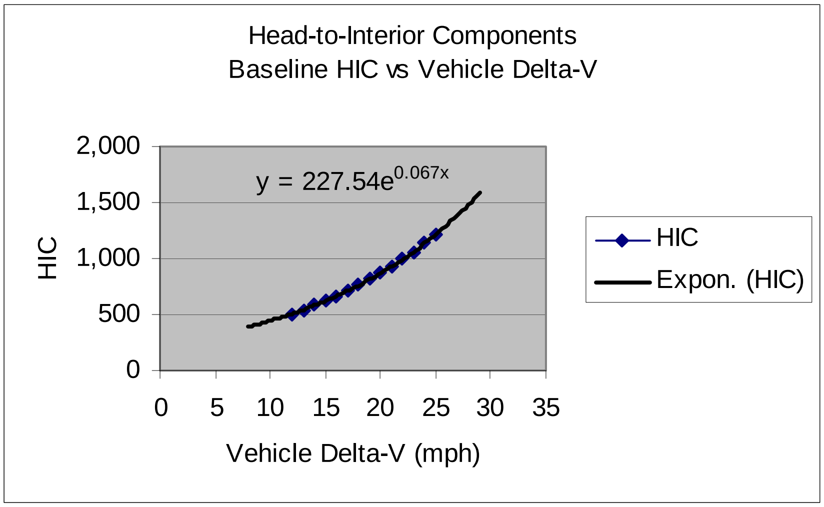

Figure B-7. Baseline HIC For Head-to-Vehicle Interior Components

Deployed HIC: The ITS HIC test results, 270 and 560 HIC scores were measured when the head of a test dummy contacts with the B pillar at vehicle delta-V's of 16.78 mph and 31.69 mph, respectively. For the case study, these test results were used as a proxy for HIC scores that would be measured when the head impacts with vehicle interior components in side crashes, as shown below:

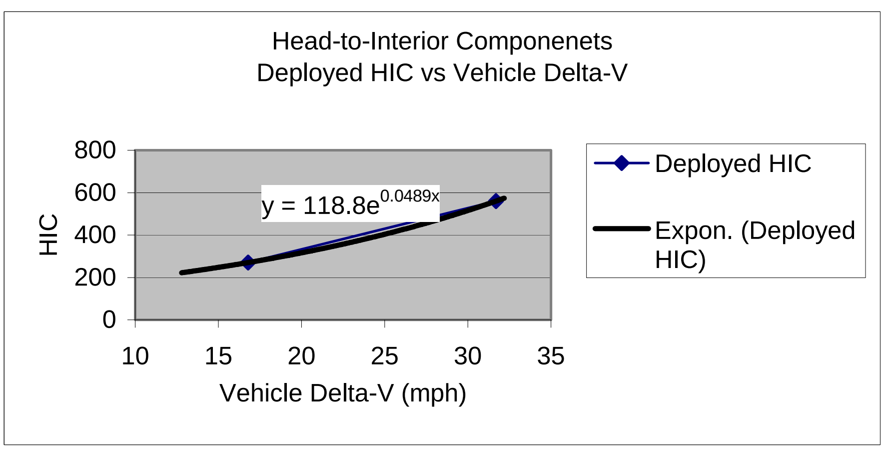

Figure B-8 Deployed HIC in Head-to-Vehicle Interior Components

Table B-13
Estimated Deployed HIC Scores
Head-to-Vehicle Interior Components
(Showing only 12 – 25 mph)

Vehicle Delta-V (mph)	Deployed HIC
12	214
13	224
14	236
15	247
16	260
17	273
18	286
19	301
20	316
21	332
22	348
23	366
24	384
25	403

ITS Bag Bottoming out Speed: The deployed ITS HIC data show a relatively low HIC score at a vehicle delta-V of 31.69 mph (occupant delta-V of 24.2 mph). Based on the head-to-pole HIC profile and the agency's 30 mph oblique pole test performed with a 2003 Toyota Camry, we believe the bag bottomed out during the impact[155]. According to the baseline HIC profile for the head-to-B pillar (Figure B-7. Baseline HIC For Head-to-Vehicle Interior Components), a HIC score of 560 would be measured at an occupant delta-V of 10.3 mph[156] when the head impacts with the B pillar. Although there are several sources that dissipate the impact energy associated with the dummy's head, the majority of the energy would be dissipated by the air bag. The

[155] If we assume that the bag didn't bottom out, the HIC would be higher than 1,200 according to the deployed HIC profile. However, the HIC measured (560) is much lower than the HIC 1,200. Therefore, the assumption is false. The head must impact the B pillar after the bag bottomed out.)

[156] At a vehicle delta-V of 13.4 mph (an occupant delta-V of 10.3 mph), a HIC score of 560 would be measured without a deployed air bag. After a bag bottomed out, therefore, a head impacts with the B-pillar with an impact speed of 10.3 mph would result in a HIC score of 560.

kinetic energy associated with the head before the impact could be expressed by the following expression:

$$KE = \frac{1}{2}(mass)(24.2)^2 \quad - \mathit{Energy\ associated}, \mathit{before\ bag\ deployment}$$

The energy associated with the head when it impacts with the B pillar at an occupant delta-V of 10.3 mph would be expressed by the following expression:

$$KE = \frac{1}{2}(mass)(10.3)^2 \quad - \mathit{Energy\ associated}, \mathit{after\ bag\ bottomed-out}$$

The energy absorbed by the bag would be expressed by the following equation:

$$\begin{aligned} \Delta KE &= \frac{1}{2}(mass)[(24.2)^2 - (10.3)^2] \\ &= \frac{1}{2}(mass)(21.9)^2 \end{aligned}$$

The equation above shows that the ITS bag would dissipate the energy associated the head up to an occupant delta-V of 21.9 mph (vehicle delta-V of 28.7 mph). Although the derivation used for the ITS bag bottoming out speed could be viewed as a somewhat simplistic approach based on an ideal system, it shows that the ITS air bag (typically, the maximum bag diameter of the ITS after inflation is about 130 –150 mm (5.1- 5.9 inches)) would bottom out a vehicle delta-V range of 25 mph to 30 mph.

As mentioned briefly, the agency performed a 30 mph oblique pole test with a 2003 model year Honda Accord equipped with a curtain air bag. Other than the impact speed, the test condition was the same as the 20 oblique pole test. The high-speed film analysis and the HIC score measured (HIC of 2,520) show that the curtain bag bottomed out during the impact. The following changes in velocity and head impact speeds with respect to the vehicle were made based on the y-component of the head and shoulder acceleration:

Table B-14
Change in Velocity
Curtain Bag, 30 mph Oblique Pole
2003 Honda Accord

	Time	Change in Velocity		
	(ms)	km/hr	m/s	mph
Head when shoulder contact the vehicle door	16.0	0.0	0.0	0.0
Head contacts with Air Bag	28.0	0.3	0.1	0.2
Head impacts with the pole	40.0	11.5	3.2	7.2

Table B-15
Head Impact Speed
Curtain Bag, 30 mph Oblique Pole

	km/h	m/s	mph
Vehicle Delta-V	48	13	30
Occupant Delta-V	37	10	23
Head at Air Bag	36.6[1]	10.17	22.7
Head at Pole	25.4[2]	7.05	15.8

1. Head at air bag = occupant delta-V – change in velocity before head contacts with air bag. (37 – 0.304 = 36.6)
2. Head at pole = occupant delta-V – change in velocity before head contacts with pole. (37 – 11.52 = 35.4)

Based on the head impact speeds at the air bag and the pole, the energy dissipated by the air bag is calculated, as shown below:

$$\Delta KE = \frac{1}{2}(mass)[(10.17)^2 - (7.05)^2]$$
$$= \frac{1}{2}(mass)(7.3)^2$$

As discussed in the ITS air bag case, the calculation shows that the curtain air bag would dissipate the kinetic energy associated with the head up to a speed of 7.3 m/s. The corresponding occupant delta-V would be 7.4 m/s (7.3 m/s + 0.1 m/s, change in velocity for the head impacts with the air bag). When the occupant delta-V is converted to a vehicle delta-V, it shows that the curtain air bag would bottom out a vehicle delta-V of approximately 22 mph. Since the curtain air bag was probably designed to meet the current 18 mph optional 201 pole test requirements, the 22 mph bottoming out speed would result in a design safety margin of approximately 16% for the curtain system tested.

When compared to the estimated 28 mph ITS bottoming speed, the curtain air bag has a lower bottoming out speed. Although we do not have sufficient data to fully analyze the difference, it appears that the difference in thickness would be a major factor that contributes to the difference. (The thickness of a typical curtain air bag is about 4 inches whereas the ITS is about nominal 5.5 inches.) According to the pendulum test performed by Volvo (ESV, paper number: 98 S8 W 29), the effectiveness (i.e., reduction in HIC) is proportional to the thickness, as shown in Table B-16.

Table B-16
HIC vs. Cell Thickness
Volvo Pendulum Test
(At a constant operating pressure of 150 kPa)

Cell Thickness	% Reduction In Thickness	Reduction In HIC
85 mm (3.35 inches)	N/A	90%
70 mm (2.76 inches)	18%	88%
55 mm (2.17 inches)	35%	84%

The effect of the bag thickness is observed in the agency's pole test as shown in Table B-7. The table shows that combo bags would have a lower HIC score when compared to curtain bags at a given delta-V. In general, similar to the ITS bag, combo bags are thicker than the curtain and would have a higher capacity of dissipating energy during an impact. Based on the ITS, the 30 mph oblique pole and the agency's 20 mph pole test results, it appears that the hypothetical

FMVSS No. 214-bag would bottom out at a vehicle delta-V of 25 mph when different types of air bags are considered.

3. Head to open/closed window

During the ITS air bag test (Docket No. NHTSA-1997-1762-017), several tests were conducted with "open" and "closed" window to investigate how glazing affects effectiveness of the air bag in side crashes. The results from the ITS test are shown below:

Table B-17
Baseline and Deployed ITS HIC Scores
With "open" and "closed" Window, (At Vehicle Delta-V of 16.78 mph)

ITS	Head Contact	HIC
No	Closed window, broken	80
Yes	ITS with Closed Window	250
No	Open Window	190
Yes	ITS with Open Window	230

The results in Table B-17 show that a deployed HIC score of 230 was measured with closed window. With open window, the HIC score decreases slightly (about 8%) at the same vehicle delta-V of 16.78 mph. The ITS test results show that the effect of glazing is insignificant in terms of HIC level at the impact speed. Note that these HIC scores are very close to the estimated deployed HIC scores from the head-to-pole and head-to-vehicle interior components, as shown in Table B-18.

Table B-18
HIC Scores with Deployed Bag
(At a vehicle delta-V of 16.78 mph)

	Speed	HIC
Open Window with ITS	16.78 mph	230
Closed Window with ITS	16.78 mph	250
Head-to-Pole	16.78 mph	254
Head-to-Interior Components	16.78 mph	270

The results in Table B-18 show that as long as the bag remains inflated, it appears, the HIC level and resulting head protection would be similar, regardless of impact objects (i.e., pole, tree or interior components).

For the baseline HIC (i.e., without deployed air bag), the results in Table B-17 show that HIC levels (80 and 190) would be very low at a vehicle delta-V of 16.78 mph, regardless of glazing. According to a report titled "Ejection Mitigation Using Advanced Glazing," (NHTSA, dated August 2001, http://www-nrd.nhtsa.dot.gov/PDF/nrd-11/glazingreport.pdf, see page 33) for any given glazing and impact configuration, the HIC responses are higher if the glass does not break. The "glazing" report states that the resulting HIC responses (from the FMH impact tests) range from 38 to 74 percent lower in the tests that produced glass fracture as compared to those that did not (based on average HIC scores). Further, the report finds that for a given glazing system and set of impact conditions, it is likely that maximum (or near maximum) HIC is achieved at the speed just below that which produces glazing fracture, and increasing the impact speed in subsequent test may not result in substantially higher HIC scores[157]. Therefore, we do not anticipate any substantial increase in HIC at higher impact speeds. When compared to the baseline HIC scores, the results shows that the ITS bag would slightly increase HIC level. However, the increase in HIC would be insignificant, in terms of head injury risk. Consequently, it would be reasonable to assume that the bag is not effective in reducing head injuries for the 12 – 25 mph delta-V range (that is considered in the analysis).

[157] The report concludes that the advance glazing tested did not significantly increase the head injury potential over standard tempered glass side windows.

We note that although the open/closed window test results show that head air bags may not be effective in reducing HIC level when there is no head contact in side crashes, they would be effective in reducing injury risk by preventing occupants from ejection in non-rollover ejection crashes. According to the ITS test report, the head of the dummy swings out through the broken window without the ITS during the impact. With the ITS deployed, the ITS prevented the dummy's head from swinging out of the broken window.

4. Head to Front of Striking Vehicle

In vehicle-to-vehicle side crashes, deformation of the striking vehicle absorbs part of impact energy. The absorption would result in a lower dummy contact speed with respect to structure of the struck vehicle, when compared to vehicle-to-pole/tree crashes. For example, in the NHTSA MDB test, the 3,000 lbs. barrier represents a striking vehicle moving at 30 mph toward the struck vehicle that is moving at 15 mph. At the compliance speed, the agency data show that a 2005 Subaru Legacy weighing 3,715 lbs. had a lateral delta V of approx. 14.5 mph. A 2005 Buick Lacrosse weighing a little over 4,000 lb. had a delta V of approximately 12 mph. These approximations are taken from acceleration data collected by the y-component of a tri-axial accelerometer placed at the c.g. of the struck vehicles. The measured vehicle delta-V's show that the use of the conservation of momentum equation would reasonably well estimate the delta-V of the struck vehicle, even without considering impact angle (i.e., 27 degree), as shown below:

Table B-19
Vehicle Delta-V in MDB Test
Actual vs. Estimated

Vehicle	Weight (lbs.)	Actual	Without considering impact angle	Adjusted with impact angle	% Error Without considering impact angle	% Error Adjusted with impact angle
2005 Subaru Legacy	3,715	14.5 mph	13.34 mph	14.97 mph	8.03%	3.12%
2005 Buick Lacrosse	4,000	12 mph	12.79 mph	14.36 mph	6.19%	16.42%

For head-to-striking vehicle case, we examined IIHS MDB test results. The IIHS MDB is heavier and taller than the agency's MDB and weighs 3,300 pounds (1,500 kg). It has a front end shaped to simulate a typical front end of a pickup or SUV. In each side-struck vehicle are two instrumented 5th female test dummies. To estimate HIC levels when the head of a dummy impact the front of a striking vehicle, two tests where the dummy's head was hit by the intruding barrier were examined: a 2003 Mitsubishi Outlander LS and a 2003 Suzuki Grand Vitara. The Outlander weighs 3,444 lbs. and the Vitara weighs about 3,280 lbs. According to the conservation of momentum equation, the vehicle delta-V would be approximately 15 mph (15.17 mph and 15.55 mph for the Outlander and the Vitara). Both vehicles were not equipped with head air bags. During the tests, HIC_{15} scores of 972 and 958 were measured for the Outlander and the Vitara, respectively. If HIC_{36} were used, we expect the HIC scores[158] would be slightly higher than ones measured with HIC_{15}. The HIC scores are shown below:

Table B-20
Estimated HIC Scores
Head Impacts with Front of Striking Vehicle
(At a Vehicle Delta-V of 15 mph, estimated)

Vehicle tested	Weight (lbs)	HIC at a given delta-V
Mitsubishi Outlander	3,444	972
Suzuki Grand Vitara	3,280	958
Average	3,362	965

The HIC results in Table B-20 show that although the risk of head injuries would be very high at a vehicle delta-V of 15 mph when head impacts with the front of a striking vehicle, the severity would be lower when compared with the head impacts with a rigid pole or tree at the same delta-V. According to the head-to-pole baseline HIC profile, a HIC score higher than 5,000 would be

[158] The 2005 Ford 500 tested in the agency's MDB test resulted in HIC_{15} scores of 47 and 192 for the driver and the rear passenger (with a 50th test dummy). When the HIC_{36} were used instead of $HIC_{15,}$ it resulted in HIC_{36} scores of 66 and 213 for the driver and the rear passenger dummies, respectively. The difference ranges from 10% to 29%.

measured when the head directly impacts with a steel pole. Unlike the head-to-pole impact, however, the 965 $_{average}$ HIC (in head-to-striking vehicle) is similar to the HIC score that would be measured in the Volvo's pendulum test. According to the pendulum test, a HIC of 1,267 would be measured at a vehicle delta-V of 15 mph, as shown in Figure B-9.

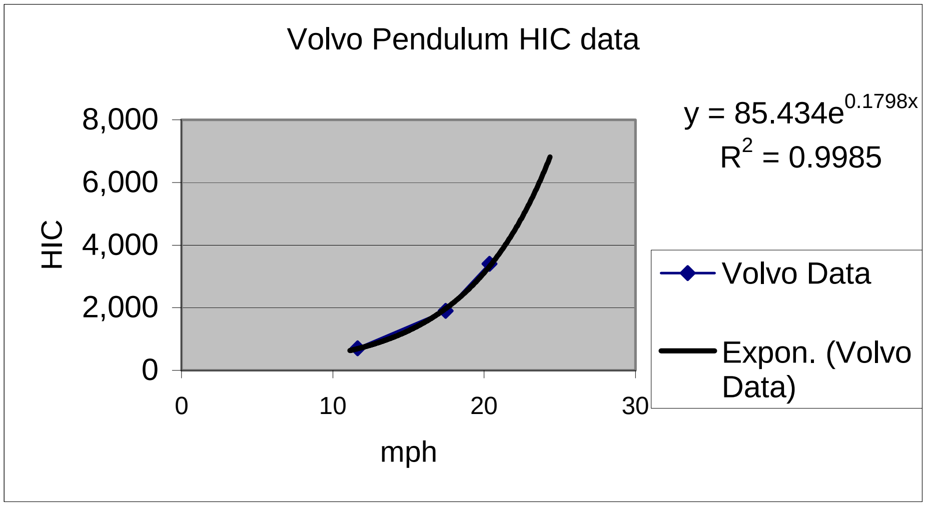

Figure B-9. Estimated HIC Profile Based on Volvo's Pendulum Test

The pendulum results and the IIHS MDB HIC measurements show that if HIC_{36} were used in the IIHS MDB test, instead of HIC_{15}, the pendulum results would very well represent the HIC level that would be measured during head-to-front of striking vehicle at a vehicle delta-V of 15 mph. For the 12-25 mph delta-V range, the HIC results from the pendulum test and the IIHS MDB tests are shown in Figure B-10.

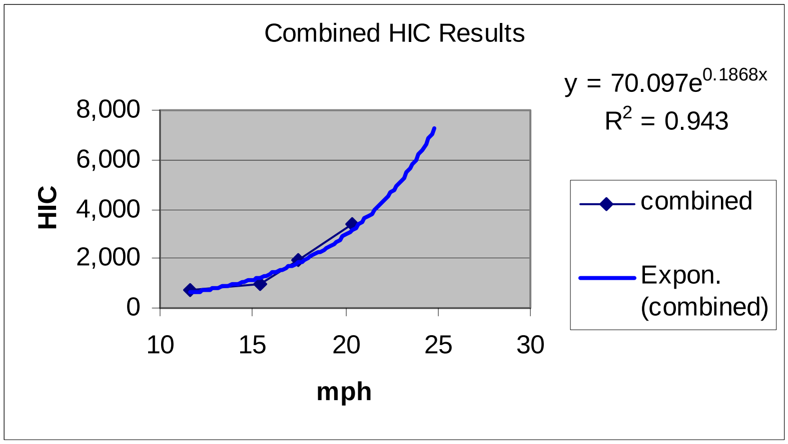

Figure B-10. Estimated HIC Scores from Pendulum and IIHS MDB Tests

Table B-21
Estimated HIC Baseline Scores
Head-to-Striking Vehicle

Vehicle Delta-V	HIC
12	659
13	795
14	958
15	1,155
16	1,392
17	1,678
18	2,023
19	2,438
20	2,939
21	3,543
22	4,270
23	5,148
24	6,205
25	7,479

Deployed HIC in Head-to-Striking Vehicle: The IIHS MDB HIC scores (972 $_{\text{Outlander}}$ and 958 $_{\text{Vitara}}$) and the pole HIC measurements show that the rigidity of impacting objects greatly influences the HIC levels. The effect also observed in the ITS test (Preliminary Regulatory Evaluation of FMVSS No. 201, April 1997, Docket No. 92-028 Notice 8), as shown below.

Table B-22
Baseline HIC and Deployed ITS HIC

Speed (km/h)	Speed (mph)	Occupant Delta-V	Head Contact	Base HIC	ITS HIC	Effect.
27	16.78	12.84	B-Pillar	700	270	61.43%
27	16.78	12.84	Window Closed	80	250	
30	18.64	14.26	Pole	2,495	331	86.73%

The results in Table B-22 show that higher HIC scores would result from the head-to-pole impact when compared to the head-to-B pillar impact, which is less rigid. However, it is intuitive that the effect would be minimal as long as the bag is in its inflated stage. For example, the results in Table B-22 show that the difference in HIC levels between the deployed ITS HIC scores is very small when the bag is in its inflated stage, regardless of impact objects (i.e., pole, B pillar or glazing). Therefore, it would be reasonable to use the head-to-pole deployed HIC profile as a proxy for the head-to-striking vehicle deployed HIC profile. The estimated deployed HIC profile for the head-to-striking vehicle is shown below:

Table B-23
Estimated HIC Scores
Head-to-Striking Vehicle

Delta-V (mph)	HIC
12	175
13	198
14	223
15	251
16	283
17	319
18	360
19	406
20	458
21	516
22	582
23	657
24	740
25	835

Appendix C
Expected FMVSS No. 201 Benefits

Expected FMVSS No. 201 Benefits and Adjusted Target Population
Vehicle-to-Pole/Tree Side Crashes

Expected FMVSS No. 201 Benefits and Adjusted Target Population

Vehicle-to-Vehicle/others Side Cashes

APPENDIX D.

IMPACTS OF ESC ON SIDE IMPACT CRASHES

This appendix analyzes the impact of the electronic stability control (ESC) on the final rule. ESC has been found to be highly effective in preventing motor vehicle crashes[159,160,161]. Furthermore, ESC is increasingly being offered as standard or optional equipment in new model year passenger vehicles. For example, the agency estimates that about 19 percent of the 2005 model year passenger vehicles were equipped with ESC (Chapter V), which is about 12 percent higher than the 2003 model vehicles[162]. However, the vast majority of vehicles in the initial target population (which consists of the entire on-road fleet) were not equipped with ESC. As ESC becomes more prevalent in the vehicle fleet, it will eliminate many of the crashes that would benefit from side air bags. Fatalities and injuries associated with these preventable crashes would thus be eliminated. To account for the ESC impacts, the agency has developed a set of adjustment factors to discount the initial target population to an appropriate level for benefit estimates. This Appendix describes the development of these adjustment factors.

The adjustment factors are determined by three basic elements: (1) the portion of initial target population that would be impacted by the ESC, i.e., ESC-impacted portion, (2) the ESC effectiveness rates, and (3) the percent of the future on-road fleet that will be equipped with ESC. The product of these three elements, i.e., the discount factor, represents the ESC benefit portion

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[159] Dang, J., Preliminary Results Analyzing Effectiveness of Electronic Stability Control (ESC) Systems, September 2004, DOT HS 809 790

[160] Farmer, C., Effect of Electronic Stability Control on Automobile Crash Risk, Traffic Injury Prevention, 5:317-325, 2004

[161] Lie A., Tingvall, C., Krafft, M., Kullgren, A., The Effectiveness of ESC (Electronic Stability Control) in Reducing Real Life Crashes and Injuries, Paper Number 05-0135, Proceedings of the 19th International Technical Conference on the Enhanced Safety of Vehicle (CD-ROM), National Highway Traffic Safety Administration, Washington DC, 2005

[162] 7 percent of 2003 model year vehicles were equipped with ESC. See footnote 1 for reference.

that should be excluded from the baseline population. The adjustment factor is merely equal to 1 minus the discount factor. It has a generic format as follows:

$$A = 1 - C * E * F \quad \text{------ (Equation D-1)}$$

Where, A = the adjustment factor

C = ESC-impacted portion,

E = effectiveness of ESC, and

F = % of the future on-road fleet equipped with ESC

The agency assumes there will be nearly 100 percent ESC installation in new vehicles by the effective date of this finale rule and assumes a baseline of 100% ESC installation to estimate the benefits of this rule. Therefore, F is 100 percent. The following sections describe the process of deriving C (ESC-impacted population) and E (ESC effectiveness rates). The value of C, the ESC-impacted population, depends on the base population that was used to derive the ESC effectiveness rates. Therefore, ESC effectiveness (E) is discussed first.

ESC Effectiveness (E)

In 2004, an agency study found that ESC is about 30 percent effective in preventing single fatal crashes for passenger cars (PCs) and 63 percent for sport utility vehicles (SUVs). For all single vehicle crashes, the corresponding effectiveness rates are 35 and 67 percent[163]. The 2004 study deployed a before-after, case-control approach using 1997-2003 FARS and 1997-2002 State Data from 5 States[164] to derive these effectiveness rates. The approach attempted to control

[163] Dang, J., Preliminary Results Analyzing Effectiveness of Electronic Stability Control (ESC) Systems, September 2004, DOT HS 809 790

[164] Florida, Illinois, Missouri, Maryland, and Utah

factors other than presence and absence of ESCs that could be associated with crash scenarios. Basically, the approach compared the number of case crashes (and control crashes) involving make-models equipped with ESCs (after) to their earlier models without ESCs (before). The case crashes contain crashes that would be affected by ESCs and the control crashes would not. In the agency approach, the case crashes were single vehicle crashes excluding pedestrians, pedalcyclists, and animals, and the control crashes were multi-vehicle crashes. The effectiveness of ESC is derived by the following formula:

$$1-\frac{f_{\text{ESC, Single}}/f_{\text{No ESC, Single}}}{f_{\text{ESC, Multi}}/f_{\text{No ESC, Multi}}}$$

Where,

$f_{\text{ESC, Single}}$ = the number of single vehicle crashes involving vehicles with ESCs,

$f_{\text{No ESC, Single}}$ = the number of single vehicle crashes involving vehicles without ESCs,

$f_{\text{ESC, Multi}}$ = the number of multi-vehicle crashes involving vehicles with ESCs, and

$f_{\text{No ESC, Multi}}$ = the number of multi-vehicle crashes involving vehicles without ESCs.

Recently, the agency extended the 2004 study to examine ESC effectiveness on multi-vehicle crashes (publication pending)[165]. There were three major changes in the updated study. First, the updated study included one more year of newly available crash data, i.e., 2004 FARS and 2003 State Data, in the analysis. In addition, a total of 7 State data[166] were used as opposed to 5 States used in the 2004 study. Second, the updated study refined the control crashes. It used a set of ESC-insensitive multi-vehicle crashes on dry roadways as the control crashes, as opposed

[165] Dang, J., Statistical Analysis of the Effectiveness of Electronic Stability Control (ESC) Systems, --- 2006, DOT HS --- --- (currently under external peer review)
[166] California, Florida, Illinois, Kentucky, Missouri, Pennsylvania, and Wisconsin

to all multi-vehicle crashes used in the 2004 study. The refined control crashes were called the non-culpable crashes on dry roadways. These crashes included, for example, a vehicle rear-ended by the front of another vehicle. Third, the updated study examined the effect of ESC on several types of case crashes including: (a) single-vehicle crashes excluding pedestrians/cyclists/animals, (b) single-vehicle rollover crashes, (c) culpable multi-vehicle crashes, and (d) non-culpable multi-vehicle crashes on wet roadways. Culpable multi-vehicle crashes include, for example, head-on crashes involving a vehicle that failed to stop or yield or crashes where the driver was charged with reckless driving or where the driver was inattentive.

The updated study found that ESC is effective in preventing single vehicle run-off-road crashes and culpable multi-vehicle crashes. The results are statistically significant, except for the passenger car (PC) effectiveness rate against culpable multi-vehicle crashes. Table 1 lists these ESC effectiveness rates by crash types (single vs multi-vehicles) and vehicle types (PCs vs SUVs). These effectiveness rates are used later to derive the adjustment factors. The ESC effectiveness rates in preventing non-culpable crashes on wet roadways are very small (not shown in Table 1) and not statistically significant. Therefore, this analysis assumes that ESC has no effect on these non-culpable multi-vehicle crashes regardless of the roadway surface conditions on which they occurred.

As shown in Table D-1, for fatal crashes, ESC is 35 percent effective in preventing single vehicle run-off-road crashes (excluding pedestrians, cyclists, and animals) for PCs and 67 percent for SUVs. For culpable multi-vehicle crashes, the corresponding effectiveness rate is 19 and 38 percent for PCs and SUVs, respectively. The 19 percent effectiveness for PCs in multi-vehicle crashes is not statistically significant.

For all crash severity levels, ESC is 34 percent effective against single vehicle run-off-road crashes for PCs and 59 percent for SUVs. For culpable multi-vehicle crashes, the ESC effectiveness rate is 11 percent for PCs and 16 percent for SUVs. Note that these ESC effectiveness rates are the mean results among the seven States.

Table D-1
Effectiveness of ESC by Crash Type and Vehicle Type

Fatal Crashes	Passenger Cars	SUVs
Single Vehicle Run-Off-Road	35	67
Culpable Multi-Vehicle	19*	38
All Crash Severity Levels		
Single Vehicle	34	59
Culpable Multi-Vehicle	11*	16

*not statistically significant

ESC-Impacted Portion (C)

As shown in the previous section, the ESC is found to be effective in preventing single vehicle run-off-road and culpable multi-vehicle crashes. This section assesses the size of the population in our initially estimated target population that would be impacted by the ESC, i.e., C - the ESC-impacted portion. The 2004 FARS was used to determine the fatal portion and 2000-2004 CDS was used for the MAIS 3-5 non-fatal injury portion. The definition used to derive the ESC-impacted fatal population is consistent with that used in the updated study for deriving the ESC effectiveness. However, CDS data were not the data sources for deriving effectiveness. Also, the variables and structures in CDS are different from those in the FARS and State Data. Therefore, the analysis cannot define the culpable multi-vehicle crashes as precisely as defined in FARS and State Data. Instead, the analysis derives a comparable definition by mapping the

CDS-variables closely to those in the FARS and State Data. The CDS variables used to define the culpable crashes included accident type, driver distraction, roadway condition, roadway alignment, weather condition, pre-crash stability, pre-crash movement, and crash avoidance maneuver. The accident type variable defined single vehicle or multi-vehicle crashes. This variable was also used to identify the pedestrian/cyclist/animal related single vehicle crashes. The remaining chosen variables were used to further define certain aspects of culpable multi-vehicle crashes such as driver inattention (the driver distraction variable), crashes on wet roadway (roadway condition and weather), or curved roadway (roadway alignment), or loss-of-control not due to flat tires and vehicle mechanic failure (pre-crash stability), or with certain pre-crash movement (e.g., negotiating a curve), or with certain steering or braking input (avoidance maneuver).

All vehicles involved in the side impact crashes were used to assess the ESC-impacted portion because any drivers' actions and any vehicles characteristics and movements would affect the outcomes of the crashes. Also, the majority of the drivers were recorded without any violation charges in FARS and CDS. Therefore, analyzing all involved vehicles provided a more accurate assessment of crash environment than just using the target vehicles (i.e., damaged on the right or left side).

Based on 2004 FARS, about 90 percent of the fatal single side impact crashes would be impacted by ESC. Of these, 66 percent were PCs and 34 percent were SUVs. For multi-vehicle side impact fatal crashes, 52 percent would be the ESC-impacted crashes. About 70 percent of the involved vehicles were PCs and 30 percent were SUVs. Fatal ejections were evenly divided between single and multi-vehicle crashes. Thus, the ESC-impacted portion for the fatal ejections is 71 percent, which is the average of the ESC-impacted portion of single vehicles and multi-vehicle crashes [i.e, = 0.5*(90+52)].

Based on 2000-2004 CDS, for MAIS 3-5 injury side impact crashes, 90 percent of the single vehicle crashes and 71 percent of the multi-vehicle crashes would be impacted by ESC. PCs comprised about 82 percent (i.e., 18 percent for SUVs) of the ESC-impacted single crashes and 80 percent (20 percent for SUVs) of the ESC-impacted multi-vehicle crashes.

Adjustment Factors (A)

As indicated in Equation D-1, the adjustment factor is equal to the difference between 1 and the product of the three basic elements. Since our initial target population is segregated into six groups by two crash severity levels (fatal, MAIS 3-5) and three crash types (vehicle-to-pole/tree, vehicle-to-vehicle/other, and complete ejection), there are six adjustment factors, one for each segment of the target population. Each adjustment factor was derived using Equation D-1 with the appropriate C, E, and F values. Substituting values for C and F is straightforward. Values derived from the previous section for C and F can be directly used. But, for E one more calculation is needed. As described in the ESC effectiveness section, the ESC effectiveness rates were derived separately for PCs and SUVs. However, the target side impact crashes comprised both PCs and SUVs. So, the weighted ESC effectiveness of PCs and SUVs should be used for E to correspond to the composition of the base population. Table D-2 summarizes the process.

As shown in Table D-2, for fatal single vehicle side impact crashes, the adjustment factor is 59 percent. In other words, ESC would prevent about 41 percent of these fatal crashes if 100 percent of on-road fleet were equipped with ESC. Similarly, the adjustment factor for MAIS 3-5 single vehicle side impact crashes is 65 percent. These adjustment factors for single vehicle crashes would apply to the vehicle-to-pole/tree type of target population. The adjustment factor is 94 percent for fatal multi-vehicle crashes and is 98 percent for MAIS 3-5 multi-vehicle crashes. These factors would apply to "vehicle-to-vehicle/other" type of target populations. The adjustment factor is 79 percent for fatal ejections and 86 percent for MAIS 3-5 non-fatal ejections.

Note that, the ESC effectiveness rates are crash based, i.e., against crashes, as are the derived adjustment factors. Since preventing a crash would prevent all injuries that resulted from that crash, it is appropriate to apply these adjustments directly to the target fatalities and injuries to derive the adjusted target population. Also, note that we don't have the ESC effectiveness specifically against MAIS 3-5 injury crashes. The estimated effectiveness rates for all crashes were used for MAIS 3-5 injury crashes.

Table D-2
Adjustment Factors for Initial Target Population
To Account for the ESC impacts

Fatal Crashes	% Impacted by ESC- (C)	% of PCs in ESC- Impacted (m)	ESC Effectiveness in % PCs (n)	SUVs (o)	Weighted (E)*	% of Fleet With ESC (F)	Adjustment Factor (A)**
Single Vehicle	90	66	35	67	46	100	0.59
Multi-Vehicle	52	70	00***	38	11	100	0.94
Complete Ejections	71	68	18	53	29	100	0.79
MAIS 3-5 Non Fatal Injury Crashes							
Single Vehicle	90	82	34	59	39	100	0.65
Multi-Vehicle	71	80	00***	16	03	100	0.98
Complete Ejections	79	81	14	33	18	100	0.86

*E = m*n + (1-m)*o
** A = 1 – C*E*F/1000000
*** Not statistically significant, treated as 0
Data sources: 2004 FARS, 2000-2004 CDS, 1997-2003 State Data

Appendix E

Derivation of Bag Effectiveness and Benefit Estimates

Appendix F

AN EVALUATION OF SIDE IMPACT PROTECTION
FMVSS 214 TTI(d) Improvements and Side Air Bags

EXECUTIVE SUMMARY

Side air bags with head protection, such as torso bags with head curtains reduce fatality risk in side impacts by an estimated 24 percent for the nearside occupant, the person seated adjacent to the struck side of the vehicle. That benefit adds to the effect of improved side structures and padding built into passenger cars during the 1980s and 90s that had already reduced fatality risk for nearside occupants by 33 percent in 2-door cars and 17 percent in 4-door cars.

In 2003, over 9,000 fatalities, approximately 29 percent of all occupant fatalities in cars and LTVs (light trucks and vans – i.e., pickup trucks, sport utility vehicles, minivans and full-size vans) began with a side impact. The side of a vehicle, especially the door area adjacent to the occupant is intrinsically a vulnerable spot: there is limited space and structure between the occupant and the outside. Side impacts can also be difficult to avoid. Even the most prudent driving on our part cannot eliminate the risk that another vehicle will fail to yield, run a red light or turn without warning across our path.

Since the 1970's, the National Highway Traffic Safety Administration (NHTSA), the manufacturers and others in the safety community have worked hard to reduce fatality risk in side impacts, especially for the most vulnerable occupant, the "nearside" occupant: the driver in a left-side impact and the right-front passenger in a right-side impact. The effort resulted in the four tangible improvements in side impact protection that are evaluated in this report:

1. Upgrading the side **structure** of passenger cars to slow down and reduce the extent of door intrusion into the passenger compartment after a side impact. Improvements include redesigning or strengthening the beams that horizontally reinforce the doors; the pillars, sills, and roof rails that surround the doors; and the cross-members or seat structures that resist lateral crush.

2. Installation of thick, energy absorbing **padding** within the door structure to reduce the probability of occupant injury after the door interior contacts the occupant.

And two types of **side air bags**:

3. **Torso air bags** that deploy from the seat or the door to provide an energy-absorbing cushion between the occupant's torso and the vehicle's side structure. Torso air bags cover a much larger impact area and absorb more energy than padding.

4. **Head-protection air bags** that complement the torso bags by cushioning head impacts with the side structure and possibly barring occupant ejection through side windows. Head protection may consist of:

a. “Torso/head combination bags” that deploy from the seat to protect the torso but also extend upward far enough to protect the head impact zones around the side window, or

b. “Head curtains” or “inflatable tubular structures” that drop down from the roof rail into the side-window area, separately from the torso bags.

During the 1980’s, NHTSA and the safety community developed a procedure for assessing injury risk in side impacts, including:

• A crash test configuration simulating a severe intersection collision in which a fast-moving vehicle strikes a slow-moving vehicle in the door, at a right angle.

• A Moving Deformable Barrier (MDB) simulating a generic striking vehicle.

• A Thoracic Trauma Index (TTI) that predicts the severity of thoracic injuries when occupants’ torsos contact the interior side surface of the struck vehicle.

• A Side Impact Dummy (SID) on which TTI can be reliably measured in side impact tests. The injury score measured on the dummy is called TTI(d).

In 1990 NHTSA amended Federal Motor Vehicle Safety Standard (FMVSS) 214, *Side Impact Protection* for passenger cars, adding a 33.5 mph impact by an MDB into the side of the car and limiting TTI(d) for a SID in the nearside position up to a maximum of 90 in 2-door cars and 85 in 4-door cars. The requirement was phased-in to passenger cars during model years 1994 to 1997 and subsequently extended to LTVs, effective in model year 1999, limiting TTI(d) to 85.

The manufacturers redesigned structures and/or affixed padding to substantially reduce average TTI(d) during and, to some extent, even before the 1994-1997 phase-in of FMVSS 214. But their actions varied from model to model. Many 2-door cars, with their long, vulnerable door areas, received extensive structural reinforcement or other redesign, whereas some of the heavier 4-door cars and most LTVs needed little or no change to meet FMVSS 214. In many cars, manufacturers improved TTI(d) well beyond the NHTSA requirements.

Manufacturers have continued to improve side impact protection by installing side air bags and/or upgrading side structures as they redesigned their cars. Torso bags first appeared on production vehicles in 1996 and head-protection air bags in 1998. By model year 2003, nearly 30 percent of new cars were equipped with torso bags and nearly 20 percent with head-protection air bags. NHTSA does not require side air bags, but encourages all improvements to side impact protection, including side air bags, by informing consumers about the performance of new vehicles. The agency’s New Car Assessment Program (NCAP) includes a rating system of one star (worst) to five stars (best) on a side impact test. *Buying a Safer Car* brochures specify what make-models are equipped with torso and/or head air bags. The information is available to consumers on the agency’s web site, www.safercar.gov.

TTI(d) performance at the 33.5 mph test speed of FMVSS 214 demonstrates how much cars have improved over the years. In 2-door cars, TTI(d) for front-seat occupants has improved, on the average, from 114 in baseline 1981-1985 models to 44 in models equipped with side air bags and meeting FMVSS 214: amazing progress on a difficult safety problem.

This report investigates if the improvements in side impact protection have saved lives in actual crashes, based on statistical analyses of crash data. The Government Performance and Results Act of 1993 and Executive Order 12866 require agencies to evaluate the benefits of their existing regulations. The statistical analyses use calendar year 1993-2005 crash data from the Fatality

Analysis Reporting System (FARS) and the General Estimates System (GES) of the National Automotive Sampling System (NASS). The analyses are divided into two main sections:

- Effect of TTI(d) improvements by structure and padding (without side air bags) on the fatality risk of front-seat occupants (drivers and right-front passengers) in passenger cars. Many of the improvements date to the mid-1990s. By now, the cars have been on the road for nearly a decade. While there is a fair amount of uncertainty, the results are essentially final in the sense that most of the eventual data are already in hand.
    - A parallel analysis for compact pickup trucks did not show a statistically significant effect.
- Effect of side air bags – torso bags and/or head-protection air bags – for front-seat occupants of cars and LTVs. Side air bags, especially head air bags began to appear in large numbers only after 2000. Analyses already show statistically significant results, but more data are on the way. The findings of this report will be updated periodically during the next five years.
    - Side air bags are principally designed to protect nearside occupants but might conceivably also benefit farside occupants: the driver in a right-side impact and the right-front passenger in a left-side impact. Statistical analyses separately focus on nearside and farside occupants.

The main findings of this report are that structural improvements and padding for cars, and side air bags for cars and LTVs have significantly reduced occupants' fatality risk. The two types of side air bags – torso bags and head-protection air bags – make substantial and complementary contributions to fatality reduction for nearside occupants. Head curtains (or inflatable tubular structures) also appear to have a significant benefit for farside occupants of passenger cars. The public will obtain the most protection if they have all of these improvements: structures and padding that meet or exceed the requirements of FMVSS 214, torso bags and head curtains. The combined effects are impressive, amounting to a 42 percent cumulative fatality reduction in 2-door cars, and a 30 percent reduction in 4-door cars.

The findings and conclusions of the statistical analyses are the following:

SIDE IMPACT PERFORMANCE OVER THE YEARS

The risk of chest injury in a side impact is measured on a specially designed side impact dummy during a crash test in the FMVSS 214 configuration, a 33.5 mph impact by a moving deformable barrier into the side of the test vehicle. Accelerations measured on the upper and lower ribs and lower spine are combined into a Thoracic Trauma Index for the dummy - TTI(d). TTI(d) gauges occupants' injury risk in nearside impacts: the lower the TTI(d), the lower the risk of injury. Reductions in the average TTI(d) of the many vehicles NHTSA has tested over the years demonstrate improved safety in side impacts.

• TTI(d) for front-seat occupants in the FMVSS 214 test configuration, by model year, averaged:

	2-Door Cars	**4-Door Cars**
FMVSS 214 requirement	*90*	*85*
Actual performance:		
1981-1985 baseline TTI(d)	114	85
1993-1996, but not yet 214 certified	95	71
1994-2003, 214-certified – no side air bags	69	63
1996-2003, 214-certified – with side air bags	44	48

• In 2-door cars, TTI(d) improved by 45 units since 1981-1985 without side air bags and an additional 25 units with side air bags, for a total of 70. Average performance was originally much worse than the FMVSS 214 requirement and is now much better.

• In 4-door cars, TTI(d) improved by 22 units since 1981-1985 without side air bags and an additional 15 units with side air bags, for a total of 37. Average performance was once about the same as the FMVSS 214 requirement and is now much better.

• TTI(d) performance used to be much worse in 2-door cars than in 4-door cars; it is now nearly the same.

EFFECT OF TTI(d) IMPROVEMENT WITHOUT SIDE AIR BAGS IN PASSENGER CARS

• During the model year 1994-1997 phase-in of FMVSS 214, approximately:

o 56 percent of cars received substantial structural modifications, usually accompanied with padding.

o 21 percent received padding with minor structural modifications.

- 6 percent received padding only.

- 17 percent remained essentially unchanged from previous model years.

• This report identifies 15 make-models that substantially improved TTI(d), by a known amount, without side air bags: from an average of 85 to 62, a 23-unit improvement. Fatality risk of nearside front-seat occupants in multivehicle crashes decreased by a statistically significant 18 percent in these models (90 percent confidence bounds, 7 to 28 percent).

• For passenger cars with TTI(d) in the below-90 range, each unit improvement of TTI(d) without side air bags is associated with an estimated 0.863 percent fatality reduction for nearside occupants in multivehicle crashes (confidence bounds, 0.33 to 1.46 percent).

- The fatality reductions for nearside occupants in single-vehicle crashes and for farside occupants were not statistically significant.

• For pre-FMVSS 214, 2-door cars with TTI(d) in the 90+ range, each unit improvement of TTI(d) was associated with an estimated 0.927 percent fatality reduction for all occupants in side impacts (confidence bounds, 0.52 to 1.33 percent).

• In 2-door cars, the cumulative effect of reducing TTI(d) from 114 (1981-1985 baseline) to 69 (post-FMVSS 214 without side air bags) is a 33 percent fatality reduction for nearside occupants in multivehicle crashes (confidence bounds, 18 to 47 percent).

• In 4-door cars, the cumulative effect of reducing TTI(d) from 85 (1981-1985 baseline) to 63 (post-FMVSS 214 without side air bags) is a 17 percent fatality reduction for nearside occupants in multivehicle crashes (confidence bounds, 7 to 27 percent).

• TTI(d) improvement by structures and padding in passenger cars saved an estimated 803 lives in calendar year 2003.

• If every passenger car on the road in 2003 had been equipped with these improvements, they would have saved an estimated 1,143 lives.

EFFECT OF SIDE AIR BAGS IN CARS AND LTVs

Nearside occupants

• Torso bags plus head protection in passenger cars reduces the fatality risk of nearside front-seat occupants in single- and multivehicle crashes by a statistically significant 24 percent (90 percent confidence bounds, 4 to 42 percent).[167]

[167] A small portion of this effectiveness may actually be due to energy-absorbing materials (other than air bags) installed to meet the FMVSS 201 upgrade of head-impact protection. NHTSA will evaluate FMVSS 201 in the future; this report only addresses its interaction with side air bags. In many make-models, the introduction of head air bags coincided with FMVSS 201 certification; nevertheless, the energy-absorbing materials remained largely

o The data also show a statistically significant fatality reduction in LTVs and suggest that the effectiveness may be the same as in cars.

o The available data do not show a difference in fatality reduction between the two types of head air bags: head curtains (or inflatable tubular structures) and torso/head combination bags.

• Torso bags alone reduce the fatality risk of nearside occupants in passenger cars by an estimated 12 percent (confidence bounds, -3 to +23 percent).

o Current data also suggest similar reductions for LTV occupants.

• Through 2005, there were few vehicles equipped with head curtains only (no torso bags): not enough for a separate statistical analysis. However, the preceding results suggest that torso bags and head air bags are both effective in nearside impacts and make approximately equal contributions to fatality reduction.

Farside occupants

• Specific mechanisms whereby side air bags mitigate injuries in farside impacts have not yet been widely demonstrated or quantified by testing.

• Nevertheless, statistical analyses of FARS and GES data show significant reductions of fatality risk for head curtains plus torso bags in farside impacts to passenger cars.

• Furthermore, analyses of life-threatening injuries to farside occupants in passenger cars without side air bags suggest that head curtains or inflatable tubular structures could have benefited unrestrained occupants – or even belted drivers if no passenger had been sitting between them and the right side of the car – because:

o Head curtains would have deployed and covered areas responsible for a large proportion of the life-threatening injuries, and

o In most of those impacts, the head curtains would still have been at least partially inflated at the time the farside occupant contacted them.

• A 24 percent fatality reduction is estimated (same as for nearside occupants) for head curtains plus torso bags in farside impacts to passenger cars – for unrestrained occupants and for belted drivers riding alone in the front seat.

• With the limited crash data available to date, no consistently significant fatality reduction was found and, for now, none is claimed in farside impacts for:

o LTVs (with any type of side air bags),

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unchanged in the year that head air bags were introduced, and for that reason could not have accounted for a large portion of the fatality reduction for those make-models in that year.

- o Torso bags alone or torso/head combination bags in cars, or

- o Belted occupants, when somebody sits between them and the far side.

Occupant ejection

• Head curtains reduced the risk of fatal occupant ejection in side impacts by a statistically significant 30 percent.

o Through model year 2003, head air bags in passenger cars were only designed to deploy in side impacts. Head curtains with rollover sensors began to appear in selected LTVs during mid-model year 2002. Crash data were not sufficient to evaluate to what extent this promising technology reduces ejections in rollover crashes.

Overall

• Side air bags could have saved an estimated 1,791 lives in calendar year 2003 if every passenger car and LTV on the road had been equipped with head curtains (or inflatable tubular structures) plus torso bags and if every LTV on the road had been equipped with torso bags plus head protection. However, the number of lives saved if all vehicles on the road were to have side air bags in a future year would be smaller than 1,791, since:

o The long-term shift of the on-road fleet from cars to LTVs will reduce the number of potentially fatal side impacts because LTVs are less vulnerable, when struck in the side, than cars.

o The increasing proportion of vehicles equipped with Electronic Stability Control will further reduce the number of potentially fatal side impact and rollover crashes by preventing these crashes altogether.

The estimation of future lives saved is beyond the scope of this report, but will be addressed in NHTSA's forthcoming Final Regulatory Impact Analysis to add a pole test to FMVSS 214.

COMBINED EFFECT OF IMPROVED STRUCTURE, PADDING, AND SIDE AIR BAGS

• Side impact protection could have saved an estimated 2,934 lives in calendar year 2003 if every car on the road had been equipped with head curtains, torso bags and FMVSS 214 side structures/padding, and if every LTV on the road had been equipped with torso bags plus head protection.

• Relative to 1981-1985 baseline cars, the combination of head curtains, torso bags and FMVSS 214 side structures/padding reduces fatality risk of drivers and right-front passengers in all side impacts by:

- o 42 percent in 2-door cars.
- o 30 percent in 4-door cars.

• In LTVs, torso bags plus head protection reduce fatality risk of drivers and right-front passengers in all side impacts by 15 percent.

Appendix G

Comments on the PEA[168]

[168] "Preliminary Economic Assessment, FMVSS No. 214, Amending Side Impact Dynamic Test, Adding Oblique Pole Test", May 2004, NHTSA, Docket No. 17694-1.

Comments were received on NHTSA's Preliminary Economic Analysis (PEA). Significant comments are discussed below, followed by our responses:

1. Maserati (Docket No. 17694-29) and Ferrari (Docket No. 17694-28) believed that NHTSA underestimated their costs to comply with the proposed rule. Maserati anticipated that the cost of meeting the pole test was between approximately $800 and $2,000 per vehicle. Maserati believed that the agency should consider the costs of research and development and "the costs for manufacturers who currently are not using any side air bag technology at all (and thus have to start 'from scratch')." Maserati also stated that NHTSA should consider the costs of changes to the structure of a vehicle. Ferrari suggested that the agency should assess the extra weight per vehicle due to the pole test and the impact on fuel economy.

Agency Response:

The agency is not persuaded by Ferrari's comments that the oblique pole test would be excessively burdensome. The agency believes that vehicle manufacturers will have ample time to redesign their vehicles to meet the new requirements. Research and development are included in the costs by using a generic markup factor from variable cost to manufacturer cost. This generic cost is based on the larger manufacturers, thus, it may not appear to be applicable to small manufacturers, if you consider any specific large program that requires large research and development costs. Small volume manufacturing is one of the reasons why costs are higher. This final rule is no different from other major rules.

The agency has not assumed or found that structural changes are needed for most vehicles to pass the test. We believe, based on the vehicles we tested, that side head and thorax air bags will be sufficient to meet the requirements. Because structural changes would not be necessary, the costs for such changes were not included in the cost estimates. We acknowledge that we have not tested a Maserati or Ferrari. However, Maserati and Ferrari did not provide any information on the structural costs they would incur. We have examined the extra weight for the side air bag systems, but not for the potential of additional structure.

2. **Target Population** The Alliance believed that the agency misidentifies the target population in the PEA. The commenter believed that the target population should include all potentially injured occupants of relatively modern vehicles. The Alliance stated that restricting the target population to serious-to-fatally injured occupants "ignores 80% of the side impact involved occupants who sustained lower severity or no injuries in the current fleet." (April 12, 2005 comment, p. 7) The commenter believed that the target population should also only select vehicles built on or after the 1990 model year. The Alliance believed that "these vehicles more appropriately represent the modern crashworthiness of vehicles with respect to side impact occupant protection countermeasures.

Agency Response:

In the FRIA we are using NASS-CDS data from 2000-2004, GES for 2004, and FARS data for 2004. These have been updated by three years from the PEA data sources of 1997-2001 NASS-CDS, 2001 for GES, and 2001 for FARS. Thus, the FRIA target population does include more relatively newer vehicles. The vehicles considered for the target population include all vehicles in these files. In order to get realistic estimates of the breakdown of crashes and injuries in tree/pole crashes versus multi-vehicle crashes with and without ejection etc., we cannot narrow our data set to just the newer vehicle model years. The sample sizes that would result would be too small to provide a meaningful analysis.

The FRIA uses modern vehicles as a baseline to estimate the effectiveness of the final rule. We recognized that vehicles produced prior to the effective dates of the FMVSS 214 MDB test may not have the countermeasures for chest protection required by the 214 MDB test. Consequently, these older model vehicles could result in relatively higher chest deflection scores when compared to relatively modern vehicles that may or may not be equipped with thorax air bags for side impacts. Accordingly, in our research tests (see final rule preamble accompanying this FRIA, section IV), we used newer vehicles that were equipped with the MDB countermeasures. Also, when we examined the performance of vehicles in protecting occupants (when we analyzed the chest deflection measured by a dummy in the tests), the examination was based on newer vehicles and the improvement offered by the MDB countermeasures and by the side air bags. These baseline vehicles would result in lower chest deflection scores when compared to older model vehicles in side crashes. We believe that a derivation based on real world crashes would result in a higher effectiveness rate when compared to the effectiveness derived in the 214 FRIA.

On the other hand, for head injuries, head air bags are relatively new and, consequently, a small portion of vehicles considered in the target population would be equipped with those particular SIABs. Therefore, an effectiveness estimate based on the results of tests of modern vehicles would be very close to an estimate of head bag effectiveness based on real world crashes. All in all, since the effectiveness rates of this FRIA are derived from tests of relatively modern vehicles, and because the majority of the estimated benefits of this final rule result from preventing/reducing head injuries, we believe that including in the target population occupant injuries from some older model vehicles does not significantly affect the overall benefit estimate of this final rule.

We believe that SIABs will provide benefits across all AIS levels; the analysis does identify the target population for all AIS levels. However, we did not include in our benefits estimate all the benefits that may result from SIABs for all AIS levels, because we do not have injury risk curves for all of the AIS levels for each of thoracic, pelvic and abdominal injuries. We have chosen in this analysis to only claim benefits in those areas we can measure. In the chest areas, these are for AIS 3 and above injuries.

3. The Alliance (Docket: NHTSA-2004-17694-32) also stated that the PEA did not provide information that allowed it to perform a complete reanalysis of the agency's process, data and conclusions, such as the selection criteria for each accident database used in the benefits analysis, or the sample size information for NASS/CDS and NASS/GES. The Alliance stated that it also did not know whether, in its estimate of the injuries prevented by the proposed rule, the PEA was considering occupants or considering injuries, was considering AIS3+ injuries or AIS 1+ injuries, why the PEA appeared to use the terms AIS and MAIS interchangeably, or why the agency assumed that AIS 6 injuries are fatal injuries (id., p. 9). Accordingly, the commenter believed that the distribution of head injury by severity presented in Table V-6 of the PEA is inconsistent with the commonly understood view that there are fewer head injuries at the higher severity (id., p. 11).

Agency Response:

The agency has put more information into the final analysis to help readers follow our analysis. We have incorporated in the FRIA the majority of the data and the derivations used in our calculations. The data and derivations are shown either in appendices or footnotes, as indicated.

Our analyses are always performed on an occupant level. That is to say, we base our analyses on an examination of the maximum injury per occupant (the MAIS), and not on an examination of all injuries that an occupant sustained. We have assumed that AIS 6 injuries are fatal injuries because almost every AIS 6 injury results in a fatality. The reason there are more severe injuries in our dataset is because our database for MAIS severity and body region injured is based on NASS-CDS, which is a towaway file. Towaway crashes are relatively severe. If you have a single-vehicle crash into a pole or tree and the vehicle is drivable, most of these crashes will not be reported to the police, and, because these crashes aren't towaways, they are not included in our files. In contrast, if you have a towaway crash in which the occupant's head has hit a pole or tree, and that head injury is the maximum injury for the occupant, you tend to have severe injuries even at a lower speed towaway.

4. The Alliance further believed that the agency should calculate side air bag effectiveness based on the injury criteria value, not on values obtained by the dummy in crash tests. For example, the commenter stated, the agency calculated the chest injury reduction rate for the target population represented by the ES-2re based on a crash test result of 30.7 mm. The Alliance believed that the calculation should be based on the criterion of 44 mm, i.e., the value that all vehicles must not exceed.

Agency Response:

This is an interesting policy issue. There are different ways to estimate the effectiveness of a standard. The agency has ranked those ways in the following order:

a) Real-world statistical analysis of databases, like FARS or NASS-CDS, or GES, or state data of a specific countermeasure.

b) Countermeasure test data utilizing injury curves to estimate effectiveness. If the countermeasure is well known, and the agency feels confident that the countermeasure will be used well into the future, we usually compare test data without the countermeasure to test data with the countermeasure (which will be below the level of the standard). Our goal is to get the best estimate of what the benefits will be from the countermeasure.

c) Countermeasure test data utilizing injury curves to estimate effectiveness. If the countermeasure is not well known, or the agency is unsure what countermeasure will be used in the future, we usually compare baseline vehicle test data to the level of the standard, assuming that the manufacturers might use a different countermeasure that just meets the level of the standard.

In this case, we believe the countermeasures that will be used to meet the pole test (side impact air bags) are very likely to be used well into the future. Accordingly, we used method (b), above, to estimate effectiveness. In estimating effectiveness, we examined both real world statistical analyses and countermeasure tests.

5. The Alliance stated that the agency did not support its assumption that the 5th percentile adult female test dummy represents 35 percent of the target population. The commenter believed that data of side-crash-involved front-outboard occupants, age 13 years or older, in model year 1985-2002 passenger cars and light trucks, in nearside impacts from 1988-2002 NASS/CDS, show that "considerably fewer than 5% of the crash-involved occupants are at or below the standing height of the 5th dummy." (p. 14) "Because the 5th dummy likely represents much less than 35% of the population, the estimated benefits associated with the proposed tests with the 5th dummy are likely overstated." The commenter also believed that NHTSA did not support its statement on page II-2 of the PEA that "small stature occupants have injury patterns that differ from those of medium stature occupants." "In fact," states the Alliance, "there are no '5th specific' aspects in the benefit estimation in the PEA for head injuries in crashes with narrow objects, which is the specific crash circumstance that the proposed oblique pole test requirement is intended to address." (p. 15)

Agency Response:

We analyzed crash data on drivers involved in side impacts to examine characteristics of drivers seriously injured or killed in pole impacts. We found in analyzing 2002 –2004 NASS-CDS crash data that smaller stature drivers (height up to 5 feet 4 inches) comprise approximately 25 percent of seriously or fatally injured drivers in narrow object side impacts. (In the PEA, the estimate was 35 percent based on 1997-2001 NASS-CDS data.)

We analyzed accident data on drivers involved in side impacts to examine characteristics of drivers seriously injured or killed in tree or pole impacts. We found in analyzing 1990-2001 National Automotive Sampling System Crashworthiness Data System (NASS CDS)[169] crash data that small stature drivers (height up to 5 feet 4 inches) comprise approximately 28 percent of seriously or fatally injured drivers in narrow object side impacts. The 1990-2001 NASS CDS

[169] NASS CDS has detailed data on a representative, random sample of thousands of minor, serious, and fatal crashes. Field research teams located at Primary Sampling Units across the country study about 5,000 crashes a year involving passenger cars, light trucks, vans, and utility vehicles.

data also indicate that there are differences in the body region distribution of serious injuries between small and medium stature occupants that are seriously injured in these side collisions. The data suggests that small stature occupants have a higher proportion of head, abdominal and pelvic injuries than medium stature occupants, and a lesser proportion of chest injuries. ("NHTSA Side Impact Research: Motivation for Upgraded Test Procedures," Samaha, et al. (2003).)

The appropriateness of an anthropomorphic test device for a dynamic test depends in part on its ability to represent occupants involved or injured in the crash simulated by the dynamic test. There are only two side impact dummies existing today representing the sizes of occupants seriously injured in side impacts: the SID-IIs and the mid-size adult male dummies (e.g., the ES-2re). The height of a small stature (5^{th} percentile) adult female is 59 inches (4 feet 11 inches). The height of a mid-size adult male is about 69 inches (5 feet 9 inches). The mid-point between the two is 64 inches (5 feet 4 inches). Drivers less than 64 inches in height are usually female and/or elderly, and are closer in physiology to a 5^{th} percentile female than to a 50^{th} percentile male. (Drivers taller than 64 inches could also be represented by the SID-IIs since driver height falls along a continuum. However, for purposes of our analysis of the impacts of this rulemaking, we had to make a cut-off and did so at 64 inches.) Accordingly, we have determined that the SID-IIs, with its height of 59 inches (4 feet 11 inches), is representative of occupants of heights up to 64 inches (5 feet 4 inches). The assumption that a 5^{th} percentile adult female dummy is representative of occupants of heights up to 64 inches (5 feet 4 inches) is consistent with the approach taken by the agency in analyzing the impacts of advanced air bags under FMVSS No. 208, "Occupant Crash Protection."

The Alliance recommended that NHTSA assume that the SID-IIs only represented occupants with a height of 47 (3 feet 11 inches) to 61 (5 feet 1 inch) inches. We believe this assumption is overly restrictive. Sixty-two-, 63- and 64- inch tall adults, mostly women, are more similar in build to the SID-IIs than to the 50th percentile male dummy.

Including the 5th percentile female dummy in the oblique pole test will gain real world benefits beyond those attained using just a mid-size adult male dummy in the pole test. We estimate that the inclusion of the SID-IIs in the oblique pole test will save additional lives beyond the fatalities saved by changes to vehicle designs to meet an oblique pole test using the 50th percentile male dummy alone. These lives lost annually of smaller stature occupants, many of whom are elderly, constitutes a safety problem that incorporation of the SID-IIs will address.

6. The Alliance stated that NPRM falls short of demonstrating a compelling need for the proposed regulation, particularly because "it ignores the voluntary actions of the motor vehicle industry to enhance occupant protection in side impacts in its benefits analysis." The commenter also believed that the benefits analysis should "consider the changes auto manufacturers are likely to make voluntarily to their products, partially in recognition of the fact that IIHS will be performing and publicizing side impact tests with their own MDB." (p. 16)

Agency Response:

This regulation is needed for safety even though the industry has made its voluntary commitment.

We have determined that this regulation will result in substantial benefits beyond those resulting from the voluntary actions of the industry. Our testing of SIABs show that some side air bags installed to meet the voluntary commitment will have to be widened and lengthened to meet our standard. Under this regulation, occupant protection will be provided to occupants' head, chest, abdomen and pelvis in both the driver and right front seating positions. The improved air bags will be more protective in oblique impacts, and will have to be more robust to protect both smaller stature and mid-size adult occupants. Because neither the industry's voluntary commitment nor IIHS's consumer information program tests with a mid-size adult male dummy, this final rule provides the only enforceable impetus to improve the level of occupant protection afforded to this population. The incremental benefits accruing from the regulation are estimated in Chapter IX of this FRIA.

In addition, this regulation is needed because an FMVSS is a mandate assuring enhanced protection to all purchasers of vehicles. The agency's enforcement authority assures that no vehicle that fails to meet the requirements of this final rule could still be offered for sale to the public. Further, decision-making on issues related to the regulation is transparent and open to public participation.

The industry's voluntary commitment has a narrower reach than this regulation. It does not expressly cover the passenger side, and is not applicable to vehicles over 8,500 pounds GVWR. Moreover, the voluntary commitment is not clear on the extent of the commitment. The voluntary commitment does not on its face commit to the installation of SIABs. It is not clear whether vehicles without SIABs that seat the test dummy high enough above the impacting barrier need be equipped with side air bags if the dummy head's will not contact the barrier in that vehicle. Thus, there is no assurance that the voluntary commitment will provide a minimum safety protection in side crashes where the vehicle impacts a tree, pole or other object.

Nearly all light vehicles will be equipped with ESC about at the same time as this final rule becomes effective. Therefore, we assumed 100 percent ESC installation as our baseline estimate and used the projected air bag sales in the analysis.

For the reasons given above, we have concluded that there is a need for this regulation, even with the voluntary commitment. We have estimated benefits and costs based on voluntary air bag installation up to the 2011 level.

7. The Alliance believed that NHTSA must estimate the benefits for the proposed changes to the MDB test. The commenter believed that without this data, it cannot be determined whether the proposed tests meet the need for motor vehicle safety. The Alliance stated that the analysis must include a breakdown of the potential benefits from the proposed 5th percentile female dummy MDB test, and from changing the 50th percentile adult male dummy currently used in the test. The commenter stated that NHTSA should consider "whether a 'worst case, single-test scenario' might be developed that could yield the same level of benefits as conducting several different tests with several different dummies."

Agency Response:

The agency has estimated the benefits resulting from use of the SID-IIs in the rear seat in the MDB test and the use of the ES-2re in the front seat of that test. Those estimated benefits are discussed elsewhere in the FRIA and in the FMVSS No. 214 final rule preamble. The ES-2re in the front seat will enhance safety at that seating position because of the dummy's enhanced abilities to measure HIC, thoracic and abdominal rib deflections, and pelvic loads. (The current FMVSS No. 214 side impact dummy (SID) does not measure HIC, rib deflections or have any type mechanism that assesses the risk of abdominal injury.)

Incorporation of the SID-IIs into FMVSS No. 214's MDB test of the rear seat enhances protection of rear seat occupants. The test of the rear seat with the SID-IIs resulted in high pelvic forces in the Honda Accord and in the Suzuki Forenza. We were concerned about these forces because rear seat occupants predominantly consist of smaller stature occupants, e.g., children, who more closely resemble the anthropometry of the SID-IIs than a 50th percentile adult male. All vehicles met all criteria when tested with the ES-2re 50th percentile male dummy. In addition, we observed that in the tests of the VW Jetta, Saturn Ion, Ford Five

Hundred, and Honda Accord, and the Suzuki Forenza,[170] the SID-IIs dummy in the rear seat of the MDB test had elevated thoracic and/or abdominal rib deflections that were not observed with the rear seat ES-2re dummy. Incorporation of the SID-IIs into the rear seat MDB test enables us to monitor readily the rib deflections measured in the test to assess how the rear seat environment is protecting children and small occupants.

Incorporation of the SID-IIs into FMVSS No. 214's MDB test of the rear seat enhances protection of rear seat occupants also because the 5th percentile adult female dummy better represents the anthropometry of rear seat occupants than the SID or the ES-2re (50th percentile male dummies). The SID-IIs's ability to assess the risk of head injury through the measurement of HIC will better ensure that head protection is provided to children and smaller stature adults in rear seating positions than through use of the 50th percentile adult male test dummies. Use of the ES-2re and SID-IIs dummies in the MDB test enhances passenger motor vehicle occupant protection in the front and rear seating positions, in accordance with §10302 of the "Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users," (SAFETEA-LU), P.L. 109-59 (Aug. 10, 2005; 119 Stat. 1144).

The agency has considered and adopted a "worst case, single-test scenario" as suggested by the Alliance, and has reduced the number of tests to one per side.

8. The Alliance believed that the benefit analysis for the oblique pole test "was not conducted in a scientifically sound and objective manner because they were based on "very limited test data." (p. 17) "Accordingly, the agency's reliance on limited test data to estimate the effectiveness of the proposed regulation is inappropriate and contrary to commonly accepted scientific practices." The commenter believed that there currently are insufficient data to fully quantify potential side air bag benefits for thorax injuries and that these benefits should not be included in the analysis until corroborated by more field data. The Alliance also believed that the agency's tests showed that the crash test results were highly sensitive to minor changes in the test parameters. "Given

[170] The Forenza was not tested with the ES-2re dummy.

this sensitivity, the agency’s projections of safety benefits, which are based on results from a very limited number of crash tests, are indeterminate and unreliable.” (p. 21)

Agency Response:

The agency has effectiveness estimates based on real world crash data and statistical analysis. Appendix F includes these estimates, which indicate that torso bags alone reduce side impact fatalities by about 12 percent. We can conclude from this that torso air bags are reducing side impact fatalities from torso injuries. The agency used the test data available to also determine effectiveness and has found reasonable agreement between these different methods.

9. The Alliance stated that we did not demonstrate the practicability of meeting the proposed test requirements, in that "no one single vehicle has been subjected to the entire suite of proposed crash tests." The Alliance believed that the agency did not demonstrate that attaining the IARVs would be practicable. Therefore, the practicability of the proposed rule has not been demonstrated."

Agency Response:

As discussed in the FMVSS No. 214 final rule preamble, we believe that it is practicable to meet the pole test requirements. In our test program, the Subaru Forester and the Honda CRV met the performance criteria for the SID-IIs dummy. The Honda Accord and VW Jetta almost met all the IARVs when tested with the SID-IIs dummy. The Accord and Jetta had relatively low values for HIC and lower spine acceleration, and did not meet only the pelvic force criterion. The Honda Accord, VW Jetta, VW Beetle convertible, and Saab 9-3 convertible met the performance criteria for the ES-2re.

It is not surprising that the vehicles we tested did not meet the IARVs for both the SID-IIs and the ES-2re, because the oblique pole test was developed to induce improvements that would protect more occupants in more crash situations than current vehicles. NHTSA need not demonstrate that any current vehicle meets all the new requirements to show that an FMVSS will be practicable within the meaning of the Safety Act when fully implemented. A determination of practicability calls for an exercise in judgment by the agency, based on information about the performance of current designs and the likely effect of design improvements and new technologies on performance.

The fact that no current designs met the requirements when tested with both the SID-IIs and the ES-2re does not show the requirements will not be practicable, but it does require the agency to use its judgment carefully to ensure that the new requirements will be practicable within the lead time provided. In this case, we have ensured that the provided lead time and phase-in schedule assures that manufacturers can make long range plans for improved sensor designs, SIABs and arm rests to meet the IARVs for both test dummies. The test results from our 2005 test program show that some SIABs performed well with the SID-IIs, while others performed well with the ES-2re. We believe that current SIAB systems can be redesigned and implemented to provide occupant protection to the populations represented by both the SID-IIs and the ES-2re test dummies. For example, some window curtains adequately protect the head of the mid-size male dummy but may need to be widened and lengthened to ensure that the head of the SID-IIs is cushioned at the forward edge of the curtain. Some vehicles may need to use a seat-mounted SIAB (existing technology), in addition to a curtain, to meet the thoracic, abdominal and/or pelvic injury criteria for both dummies. We believe that vehicle manufacturers are capable of making these and other improvements to SIAB systems.

Manufacturers have made steady and notable progress in developing, improving and implementing SIABs. To illustrate, in 1998, only 0.04% of passenger cars sold in the U.S. had head side air bag systems. In 2002, 22% of passenger cars were so equipped, and by 2009, under the voluntary commitment, manufacturers have projected that 100% of passenger vehicles will have head side air bag systems. Based on the vast knowledge that manufacturers have been able to gain in developing and implementing side air bag technologies, we are confident that manufacturers will be able to make the improvements to current systems that will enable the systems to meet the upgraded FMVSS No. 214 requirements adopted today.

10. Data Quality

The Alliance stated that the substance and presentation of the data in the PEA does not meet the principles set forth in the Data Quality Act and the corresponding DOT Guidelines. "The data in the PEA are not sufficiently objective …because it [sic] contains numerous errors, unsupported assumptions, and un-reconciled inconsistencies." The Alliance stated that an unsupported assumption was that curtains will mitigate total occupant ejections, and that curtains will provide benefit in rollover crashes. The Alliance also believed that the agency assumed, based in HIC results in the 32 km/h (20 mph) pole test, that all head impacts with a pole in the delta-V 12-to 25 mph range will result in a fatality, and that this assumption was incorrect given field data in Table V-6 of the PEA that showed that vehicle-to-pole side impacts have not all resulted in a fatality.

Agency Response:

The agency did not assume any of the claims made above. Accordingly, we find that the commenter's challenges under the Data Quality Act (DQA) for those particular claims are without merit.

Furthermore, to the extent that the Alliance is challenging the PEA on a generalized basis by referring to "numerous errors, unsupported assumptions, and un-reconciled inconsistencies," under the DOT guidelines implementing the Data Quality Act, DQA challenges must provide a clear identification of the specific information that the affected person wants NHTSA to correct. DQA challenges also need to provide a detailed description specifying why the affected person believes the information in question is inconsistent with DOT's information quality guidelines. If there is no clear identification of the specific information at issue, it is very difficult or impossible for the agency to respond to the challenge in a productive manner. In addition, general or unfocused assertions are also not persuasive. For these reasons, we do not consider the Alliance's general statements disagreeing with the PEA as challenges suitable for redress under the DQA.

In any event, we strongly believe that the FRIA is fully consistent with the principles of the DQA and implementing DOT guidelines. The analysis is based on sound statistical analyses and economic principles generally accepted in those professional communities. All the methodologies, hypotheses, and data used for the analysis are transparent (except as granted confidentiality by the agency[171]) and have been documented in detail in this FRIA. Data sources are fully identified in the analysis. Data were obtained from NHTSA's real-world crash data systems, which meet high standards for data quality, integrity and accessibility. Data were also obtained from laboratory crash tests which were meticulously conducted using objective and repeatable test procedures. In sum, the data supporting this final rule have been determined to be are accurate, reliable, and unbiased, and the analysis presents the information in a clear, complete, accurate, and unbiased manner. Accordingly, the agency concludes that the FRIA meets the objectives of the DQA and DOT's implementing guidelines.

11. The Alliance also believed that it was incorrect for the agency to assume that "side airbags are 100% percent effective for 12-25 mph, across all collision partners for the entire fleet" and that all head injuries resulting from non-rollover side window ejection cases were considered as a narrow object impact case in terms of HIC level. Further, the Alliance stated that an unsupported assumption was that sensors and other mechanical and electronic devices will perform their designed functions over the vehicle's operational lifetime.

Agency Response:

The agency does believe that, in this delta V range, with properly deployed air bags it is possible to reduce head-related fatalities by nearly 100 percent. Non-rollover side window ejections can't be any worse than your head hitting a pole at 20 mph. Keeping occupants in the

[171] Manufacturers' plans for installing side air bags on vehicles.

vehicle will have major benefits. The agency has no reason to believe or data to support an assumption that sensors will not last the vehicle's lifetime.

12. Alliance comment on the Sensitivity Analyses of the PEA
The Alliance commented on the sensitivity analyses of the PEA (Chapter XI), stating that the analysis "most likely overstate[d] the estimated benefits." (p. 27) The commenter believed that the sensitivity analysis considered only a decreasing effectiveness rate of SIABs between 20 and 30 mph. The commenter believed that frontal air bag effectiveness studies have shown that effectiveness "to be a maximum velocity between one-half and one-third of the test velocity. [Footnote omitted]." (P. 28 of comment). The Alliance also believed that studies suggest that frontal air bag effectiveness is primarily at the tested angle, so NHTSA failed to adequately discount for SIAB effectiveness at angles other than 75 degrees.

Agency Response:

It is true that frontal air bag effectiveness is different at different angles and velocities. The near side head striking a pole is a different kinematic than in frontal impacts. We don't believe that once the air bag is between the head and the pole, that the angle will matter much, or that the speed will matter much until the air bag bottoms out. We have chosen 25 mph, based on limited test data and analysis as the speed up to which the current width air bags should work.

13. The Alliance also believed that no fatalities associated with thoracic injuries should be included among equivalent lives saved (comment, p. 29), and that the effectiveness in preventing facial/head injuries most likely is not 99.9% as set forth in the PEA. The Alliance stated that, "Adjusting the target population based upon the three factors discussed above…results in a negative estimated net benefits for both of the two cost-per-equivalent-lives-saved values set forth by the agency in the PEA. These negative benefits estimates indicate that the cost of the agency's proposed regulation greatly exceed the benefits."

Agency Response:

The agency is finding a fatality benefit for thoracic air bags in its real world statistical analysis. Thus, there is every reason to assume that thoracic air bags will prevent fatalities.

14. The Alliance commented on the probabilistic uncertainty analysis (Chapter XII), stating that it was unclear why the agency included a benefit estimate of 82 fatalities in its model when the agency stated elsewhere in the PEA that there was insufficient field data to fully quantify the

effectiveness of SIABs in preventing fatalities associated with thoracic injury. The commenter also believed (comment, p. 32) that the agency overestimated the number of prevented fatalities that are associated with facial/head injury. The commenter also stated that some factors, such as direction of force and crash speed, were not considered as potentially significant factors ("decreasing the side impact target speed from 12-25 mph to 12-20 mph will reduce the target population about 40%"). The Alliance also stated that the adjustment factor for current side air bag benefits was not adequately defined (p. 33).

Agency Response: These issues have been addressed above and the adjustment factor for current side air bags has been added into the FRIA.

15. Head Injuries Occurred Inside & Outside Vehicles.
The Alliance, in their comments on the PEA, Docket # NHTSA-2004-17694-52, claimed the methodology ignores that risk of particular types of crashes in the real world and the resultant injury sources in those variable crashes.

Agency Response:

As the commenter brought up, when a certain crash occurs, such as a vehicle-to-pole impact, the likelihood of the head impacts with interior components, exterior objects or open/closed window would be affected by many factors, such as relative positions of the head, impact angle and speed. Since the publication of the PEA, the agency investigated injury sources in real world side crashes. The investigation revealed that, for example, the fatal injuries in vehicle-to-pole/tree side crashes, the injury sources data show that 17.5% of all fatalities occurred in the crashes were resulting from impacts with the exterior of other vehicles, as shown below:

Table G-1
Front Occupant Injury Sources[1]
Fatalities Occurred Inside Vehicle
For 12 –25 mph Non-rollover Side Crashes
By Crash Type

Vehicle-to-Vehicle/Others:	
Steering Wheel Rim and Hub/Spoke	4.0%
Left Side Interior Surface (no hardware)	15.9%
Left Side Interior Hardware/Armrest	14.9%

Left A/B Pillar (Majority B Pillar)	5.3%
Right Side Interior Surface	20.2%
Right A/B Pillar	7.8%
Other Interior (e.g., Roof, Floor)	4.3%
Exterior of other vehicle	17.5%
Non-Contact	3.7%
Unknown Sources	6.4%
Total	100.0%

The 2000 – 2004 FARS crash data show that a total of 1,882 fatalities occurred in vehicle-to-vehicle/others side crashes in a delta-V range of 12 –25 mph, annually (after adjusted with the Electronic Stability Control (ESC) potential benefits). Among these fatalities, 631 were resulting from head/face injuries. Among the 631 head/face fatalities, the fatal injury sources show that 329 would be from head-to-exterior of the striking vehicle and 247 would result from head impacts to the A or B pillars in non-rollover vehicle-to-vehicle side crashes for the delta-V range considered (13.1% of all injuries occurred).

16. Electronic Stability Control (ESC).
DaimlerChrysler commented that the PEA has not recognized the benefits of Electronic Stability Control (ESC) in reducing loss of control in side impacts with narrow objects (Docket # NHTSA-2004-17694-53).

Although a small fraction of vehicles on the road are equipped with ESC, our preliminary data show that ESC has a relatively high effectiveness rate in preventing crashes (i.e., helping to prevent skids, spinouts and rollovers). Under the proposed FMVSS No. 126, "Electronic Stability Control Systems," we expect all MY 2011 vehicles will be equipped with ESC. For this analysis, therefore, we adjusted the target population with the potential ESC benefits based on 100% ESC installation.

According to the agency's data, ESC is highly effective in preventing crashes in both single and multiple vehicle crashes. The data show that the ESC is about three times more effective in single vehicle crashes (SVC) than multiple vehicle crashes (MVC) and that SUVs have a higher ESC effectiveness rate[172] when compared with passenger cars. According to FARS (2000-2004), we determined that ESC has 46% and 11% effectiveness rates in preventing crashes in side crashes, respectively, as shown below:

Table G-2
Adjustment Factors for Initial Target Population
To Account for the ESC Impacts, Fatal, SVC

Crashes (fatal)	% of total vehicle involved	ESC Effec.		Weighted ESC Effec.	% of Fleet with ESC	Population impacted by ESC	ESC affected fleet
PCs	66%	35%		46%	100%	90%	41%
LTVs	34%	67%					

Table G-3
Adjustment Factors for Initial Target Population
To Account for the ESC Impacts, Fatal, MVC

Crashes (fatal)	% of total vehicle involved	ESC Effec.		Weighted ESC Effec.	% of Fleet with ESC	Population impacted by ESC	ESC affected fleet
PCs	70%	0%		11%	100%	52%	6%
LTVs	30%	38%					

The target population was categorized into two groups: vehicle-to-pole/tree and vehicle-to-vehicle side crashes. The target population adjusted with the ESC benefits is shown in Table G-4.

Table G-4
Target Population Adjusted with ESC Benefits
By Crash Mode

Crash	Reduction in Target Population	
	Fatal	Serious Injuries
Vehicle-to-pole/tree	41%	35%
Vehicle-to-vehicle/others	6%	2%

[172] ESC Effectiveness for both passenger cars and SUVs are based on state crash data (Florida, Maryland, Missouri, and Utah), 1997-2002, and also FARS, 1997-2003 data. According to the state data, passenger cars have a total effectiveness of 30.86% whereas SUVs have a total effectiveness of 60.90%. The FARS data show that passenger cars have a total effectiveness of 29.52% and SUVs have a total effectiveness of 62.56% in side vehicle crashes.

17. Oblique Impacts in Real World Crashes.

In its comment, Docket NHTSA-2004-17694-53, page 14, DaimlerChrysler said, "we are aware that the NHTSA has encountered specific cases where a vehicle designed to meet the 90-degree pole impacts failed to detect the 75-degree oblique pole impact. Generally, sensing robustness relative to a range of impact locations and angles has to be one aspect of engineering for side impact protection. While NHTSA has created this situation in its laboratory testing, we are not aware of this as a real world issue."

Agency Response:

The agency's test results show that there is a clear indication that head air bags (and probably thorax bags) designed for the 90-degree pole impact need to be widened, or the sensors enhanced to detect an oblique impact. Thus, we believe the 75-degree oblique pole impact is needed to protect occupants in a wider range of side crashes.

Subsequent to the publication of the PEA, the agency investigated real world side crashes where the side air bag did not deploy, as shown in Table G-5. Note that the rows highlighted in the table are crashes in which we believe the side air bag would have deployed had the vehicle met an oblique pole test, based on our experience in investigating crashes. The Tahoe crash[173] (Case number: 2004-47-156) investigation shows that a narrow impact object impacted the front part of the door, near the A-pillar. The side impact sensor, on the B-pillar, apparently did not deploy the air bag. The Tahoe crash is similar to the oblique side impact pole test where the pole (aimed at the head of a 5th female test dummy when it was sitting full forward) impacts the front part of the door, near the A-pillar.

The results of the crash investigation suggest that, to meet the oblique pole test, some manufacturers would need to provide 2 crash sensors on each side of the vehicle, one on the side

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[173] The Tahoe has one side impact sensor at each front door, "The Rescuer's Guide to Vehicle Safety Systems," holmatro, 2nd edition.

rail near the center of the front door and one on the side rail near the center of the rear door, or redesign their sensors.

Table G-5
Side Impacts Into A Tree or Pole With Side Airbag Non-deployment
2002-2005 Sample Year
(Data Run 5/3/2005)

Case	Veh. Num.	Vehicle	Delta-V (mph)	**Comments**
2002-47-081	1	2000 BUICK REGAL	UNK.	Sideswipe
2002-48-073	1	2001 GMC FULLSIZE JIMMY/YUKON	UNK.	Sideswipe Non-Horizontal
2003-02-063	1	2002 CHEVROLET TRAILBLAZER (2002 and later)	UNK.	Minor Damage
2003-09-018	1	2001 MITSUBISHI MONTERO	7.5	
2003-09-232	1	2001 LINCOLN NAVIGATOR	5.6	
2003-41-110	1	2002 HONDA ACCORD	33	80º PDOF
2003-43-155	2	1997 INFINITI Q45	UNK.	Minor Damage
2003-43-201	1	2002 ACURA RSX	9.3	
2003-43-263	1	2002 GMC JIMMY/TYPHOON/ENVOY	6.8	
2003-45-209	1	2004 MERCEDES BENZ SE,CD,D,SD,ETC	5.6	
2003-49-082	1	2003 NISSAN / DATSUN ALTIMA	MOD.	
2003-49-181	1	2000 CHEVROLET FULLSIZE BLAZER (K, Tahoe)	UNK.	Non-Horizontal
2003-73-176	2	2003 HONDA PILOT	UNK.	Sideswipe
2003-82-079	1	2002 VOLKSWAGEN JETTA	UNK.	Sideswipe
2004-02-084	1	2004 HONDA CR-V	UNK.	Sideswipe
2004-04-024	1	2003 SUBARU IMPREZA	MOD.	80º PDOF
2004-04-101	2	2003 HYUNDAI SANTA FE	13.7	50º PDOF
2004-11-213	1	2003 FORD CROWN VICTORIA	8	
2004-12-191	2	2000 CHEVROLET LUMINA APV/VENTURE	7.5	10º PDOF
2004-13-079	1	2003 FORD THUNDERBIRD (ALL SIZES)	UNK.	Minor Damage
2004-47-156	1	2002 CHEVROLET FULLSIZE BLAZER (K, Tahoe)	13.7	290º PDOF, Behind A-Pillar
2004-49-006	1	2001 HYUNDAI SONATA	UNK.	350º PDOF
2004-49-027	2	2000 CADILLAC DEVILLE/FLEETWOOD	31	50º PDOF
2004-79-001	1	2003 LINCOLN LS	17.4 7.5	320º PDOF
2004-81-091	2	2003 CHEVROLET TRAILBLAZER (2002 and later)	5	
2005-08-040	2	2002 BUICK LESABRE/CENTURION/WILDCAT	1.9	
2005-13-045	1	2000 HYUNDAI SONATA	17.4	280º PDOF
2005-50-006	1	2001 HYUNDAI SONATA	MOD.	100º PDOF
2005-50-036	1	2002 TOYOTA AVALON	18	40º PDOF
2005-74-038	2	2003 HONDA ACCORD	UNK.	Non-Horizontal

Note: MOD: moderate; UNK: unknown

18. **NHTSA notes**: On November 1, 2005, almost seven months after the closing date for comments on the proposed rule, the Alliance submitted to NHTSA a document dated October 11, 2005, consisting of a page-by-page listing of several hundred points that the Alliance raised about the PEA. These comments generally repeated, in a detailed manner, the points the Alliance had already raised in their April 12, 2005 comments on the PEA, which this FRIA addresses. We note that while the Alliance questioned some of the PEA's assumptions, the Alliance's submissions did not provide any information that corrected, supplemented or could be used by the agency to revise those assumptions.