U.S. Department of Transportation
National Highway Traffic Safety Administration

Memorandum

NHTSA
WASHINGTON, DC 20590
2004 MAY 12 A 11:59
OFFICE OF CHIEF COUNSEL

Subject: ACTION: Preliminary Economic Assessment FMVSS 214, Side Impact Oblique Pole Test

Date: MAY 12 2004

From: Noble N. Bowie [signature] for
Associate Administrator
for Planning, Evaluation and Budget

Reply to Attn. of:

2004 MAY 14 A 10:39
DEPT OF TRANSPORTATION DOCKETS

To: Docket NHTSA-2004-17694
Thru: Jacqueline Glassman [signature] for
Chief Counsel

Please submit the attached "Preliminary Economic Assessment, FMVSS No. 214, Amending Side Impact Dynamic Test Adding Oblique Pole Test", May 2004, to Docket No. NHTSA-2004-17694.

Attachment

Distribution:
Senior Associate Administrator for Vehicle Safety
Associate Administrator for Rulemaking
Associate Administrator for Vehicle Safety Research
Associate Administrator for Enforcement
Chief Counsel

#

U.S. Department
Of Transportation

People Saving People
http://www.nhtsa.dot.gov

PRELIMINARY ECONOMIC ASSESSMENT

FMVSS NO. 214
AMENDING SIDE IMPACT DYNAMIC TEST
ADDING OBLIQUE POLE TEST

OFFICE OF REGULATORY ANALYSIS AND EVALUATION
PLANNING, EVALUATION AND BUDGET
MAY 2004

TABLE OF CONTENTS

Executive Summary E-1

I. Introduction I-1

II. Background II-1

III. Injury Criteria III-1

IV. Test Data and Analysis of Pole Test Data IV-1

V. Benefits V-1

VI. Technical Costs and Lead Time VI-1

VII. Cost-Effectiveness and Benefit-Cost Analyses VII-1

VIII. Test Data and Analysis of Moving Deformable Barrier Test. VIII-1

IX. Alternatives IX-1

X. Regulatory Flexibility Act and Unfunded Mandates Reform Act Analysis X-1

XI. Sensitivity Analyses XI-1

XII. Probabilistic Uncertainty Analysis XII-1

EXECUTIVE SUMMARY

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

Test Requirements

We propose a new 20 mph, 75-degree oblique pole test run in two different configurations, one with a 50^{th} percentile male (ES-2re) dummy and the other with a 5^{th} percentile female (SID-IIs FRG) dummy. In addition to the oblique pole test, the NPRM proposes tests with the ES-2re and the SID-IIs FRG in the moving deformable barrier (MDB) dynamic FMVSS 214 side impact test, in place of one test with the 50^{th} percentile SID.

Countermeasures

The agency believes that side air bags for the head and thorax will be used to pass the proposed tests and that most manufacturers will have to make their current side air bags wider to pass the oblique test. We analyze 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 combination head/thorax side air bag system is the least expensive of the countermeasures examined. The agency does not know whether a wider combination head/thorax side air bag could meet the Technical Working Group's (TWG) recommended voluntary testing for out-of-position children. However, some current combination head/thorax side air bags are very close to the size we predict will be needed to pass the proposed test. The agency believes that a wider thorax side air bag could pass the TWG and could be used in combination with a wider window curtain for head protection.

The agency could not identify any specific countermeasures with costs and benefits for adding the 5th percentile female moving deformable barrier test. This test will help assure that smaller sized occupants are protected to the same extent as the 50th percentile male occupants. Countermeasure designers may have to pay more attention to how far window curtains come down the window, the armrest designs, possibly padding in the door, etc.

Benefits

The agency estimates that in a fleet not equipped with head and/or thorax air bags, but meeting FMVSS 201 upper interior head protection requirements, there would be 2,910 fatalities and about 46,000 injuries, of which 7,248 are AIS 3-5 injuries, among occupants in front outboard seating positions in near-side crashes of 12-25 mph delta-V in vehicle-to-pole, vehicle-to-vehicle and non-rollover crashes with complete occupant ejection.

After adjusting for assumed full compliance with the FMVSS 201 upper interior requirements, increased safety belt usage to 79 percent observed usage in 2003, and current compliance with the proposal (based on an estimate of MY 2003 vehicles with side air bags), the incremental benefits of the proposal are estimated as shown in the following table.

Benefits of the Proposal by Countermeasure

	Combination Air Bag 2 Sensors	**Curtain & Thorax Bags 2 Sensors**	**Curtain & Thorax Bags 4 Sensors**
Fatalities	686	1,027	1,032
AIS 3-5	880	999	1,037

Window Curtains are estimated to have more benefits than combination air bags because we assume that window curtains will have an impact on ejections that occur in side impacts without rollover, while we assume no benefits for combination air bags in ejections without rollover. Combination air bags probably will have some benefit in non-rollover 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 require a rollover sensor to deploy the bags in rollovers. The majority of the benefits are for front seat occupants, however, head injury benefits are included for rear seat occupants for the window curtains.

Costs

Potential compliance costs for the proposed 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 a wide combination head/thorax side air bags with two sensors at $121 per vehicle to wide window curtains and wide thorax side air bags with four sensors at a cost of $264 per vehicle. Given the level of compliance in the MY 2003 fleet, the average vehicle incremental cost to meet this proposal with the lower cost combination air bag is estimated to be $91 per vehicle and with the wide window curtains and wide thorax side air bags with four sensors is estimated to be $208 per vehicle (2002 dollars). This amounts to a range of total incremental annual cost of $1.6 to $3.6 billion.

Incremental Total Costs and Average Vehicle Costs
($2002)

	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	$1.6 billion	$3.0 billion	$3.6 billion
Average Incremental Cost per Vehicle	$91	$177	$208

Net Cost Per Equivalent Life Saved and Net Benefits

Estimates were made of the net costs per equivalent life saved. The low end of the range is $1.8 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 $3.7 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

	Combination Head/Thorax Side Air Bags	**Window Curtain and Thorax Side Air Bags 2 Sensors**	**Window Curtain and Thorax Side Air Bags 4 Sensors**
Cost Per Equivalent Life Saved			
3% Discount Rate	$1.8 million	$2.6 million	$3.0 million
7% Discount Rate	$2.2 million	$3.2 million	$3.7 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 $1,447 million for the combination head/thorax air bags using a 3 percent discount rate and the low end is negative $202 million for the curtain + thorax bags with four sensors, using a 7 percent discount rate. Both of these are based on a $3.5 million cost per life, as shown below.

Net Benefits
With $3.5M Cost Per Life
(in millions)

Countermeasure	Benefit		Net Benefit	
	3% discount	7% discount	3% discount	7% discount
Combo + 2 Sensors	$3,010	$2,457	$1,447	$894
Curtain + 2 Sensors	$4,116	$3,360	$1,073	$317
Curtain + 4 Sensors	$4,141	$3,378	$561	-$202

Uncertainty

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 $3.5 million and for the separate window curtain/side thorax air bag with two sensors we found 75% certainty that the cost per equivalent life saved will be less than $3.5 million at a 7% discount rate. In addition, the analysis shows that the three countermeasure systems would have a 100% chance to produce a cost per equivalent life saved of no more than $5.5 million.

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[1] with a gross vehicle weight rating (GVWR) of 2,722 kg (6,000 pounds) or less. This test currently provides protection against thoracic and pelvis 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 50^{th} 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, the potential for head injury is not measured in the dynamic FMVSS 214 test procedure. 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

---

[1] 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 head form propelled at specific target points in the vehicle at 15 mph.

In 1998, NHTSA published a final rule 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 systems had to undergo 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.

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.

This NPRM would 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 proposed pole test will be conducted using a 5^{th} percentile female dummy (SID-IIs) seated full-forward or a 50^{th} percentile male dummy (ES-2re) seated at the mid-track position of the front outboard driver or passenger seats. The agency is also proposing that the same dummies seated in the same manner be used in the MDB test configuration required by FMVSS 214.

This Preliminary Economic Assessment presents the agency's estimates of the potential benefits and costs of countermeasures that could meet the proposed pole test. It provides analysis of the different dummies that could be used during the test and discusses the proposed injury criteria. It provides analyses of the different tests and alternatives the agency considered. Finally, it estimates the cost per equivalent life saved.

In the NPRM, the agency is asking for comments on some of the alternatives not being proposed. These include using the SID-H3 50^{th} percentile male dummy instead of the ES-2re, having a perpendicular pole test instead of an oblique pole test, having a MDB test similar to the IIHS test procedure, and a pass/fail criteria for the ES2-re rib deflection in the range of 38 to 44 mm, instead of the proposed level of 42 mm.

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 proposes to employ an oblique pole test aimed at the head of a front seat occupant (either the driver or right front passenger) using crash dummies representing a 50^{th} percentile male (ES2-re) and 5^{th} percentile female (SID-IIs FRG). The proposed oblique pole test would require protection for the head, chest, abdomen and pelvis when a vehicle impacts with a pole 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 proposed requirements.

In addition to the oblique pole test, the agency is proposing to upgrade the 50^{th} percentile male dummy to the ES-2re for the moving deformable barrier (MDB) dynamic FMVSS 214 side impact test, and additionally, include a 5^{th} percentile female dummy (the SID-IIs FRG) in the test procedures. Currently, the SID dummy is used. The agency is proposing to use the ES-2re as the 50^{th} percentile male dummy, but is seeking comments on the SID-H3. The injury criteria in the MDB test are the same as those proposed for the vehicle-to-pole test.

Dummies

The 1990 amendment to FMVSS 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 tentatively concludes 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. Therefore, the agency proposes that a 5th percentile female SID-IIs FRG crash test dummy be used in both the vehicle-to-pole and MDB-to-vehicle 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 and neck 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 and neck 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 individually, 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 5^{th} percentile dummy seated full forward, that not every vehicle's side impact sensors pick up 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 used that 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 the combination head/thorax 2 sensor system and the window curtain, side thorax 2 sensor air bag system. Only a few vehicles have a window curtain, side thorax 4 sensor air bag system. However, this 4 sensor system could become more prevalent if 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 proposal 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 pass this proposal. 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, 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 proposal is only for front seat protection, thus, there is no need for a combination head/thorax air bag for the rear seat.

Benefits include front seat occupants in vehicle-to-vehicle and pole/tree impacts, no benefits for ejections are included for combination head/thorax air bags.

<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 window curtains for the front and second seat and separate thorax side air bags for the front seat only. The system includes two sensors per vehicle on the side rail near the front door.

Benefits include front seat occupants in vehicle-to-vehicle, pole/tree impacts, and ejections without rollovers. Rear seat occupant benefits for the head include vehicle-to-vehicle and ejections without rollovers, no benefits are included for pole/tree impacts for the rear seat occupants because we assume that narrow object impacts in the rear area will not be sensed by the forward sensor.

The window curtain for the front and rear seat, side thorax air bag for the front seat, 4 sensor system

The countermeasure for this approach will be window curtains for the front and second seat and separate thorax side air bags 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 side rail near the rear door. A few manufacturers have a 4 sensor system currently.

Benefits include front seat occupants in vehicle-to-vehicle, pole/tree impacts, and ejections without rollovers. Rear seat occupants benefits for the head include vehicle-to-vehicle, pole/tree impacts, and ejections without rollovers

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 proposal. 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 concerned about the potential injury impact that side thorax air bags could have on children in the rear seat. That is one of the reasons that the agency is not proposing a pole test for rear seat occupants.

So, the three countermeasure systems we are analyzing in this analysis are:

	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 proposed 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.

Not all of the thorax air bags, combination air bags, and window curtains were wide enough to provide the protection desired in the oblique impacts, and particularly when the 5th percentile female dummy was seated full forward in the oblique impact. 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 proposed test conditions. The agency has not designed and produced such systems, however, it appears to be well within the engineering capability of the air bag suppliers. The only concern we have is 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.

Regarding the proposed MDB test, two vehicles, the 2001 Focus and 2002 Impala, were tested according to the FMVSS No. 214 MDB test procedure specified in the standard and the ES-2re in the driver and rear passenger seating positions. The results show that the Ford Focus met the proposed MDB test requirements when tested with the ES-2re dummy and its associated injury criteria. The results also show that the 2002 Chevrolet Impala did not meet the proposed abdominal force criterion. An examination of the passenger compartment interior revealed that the rear armrest design and location may be the problem[1]. 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

[1] 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) above the seat surface.

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 Focus. However, this particular modification may reduce the rear seat width by a small amount.

III. INJURY CRITERIA

This section contains a description of the proposed 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 proposed for the 50th percentile male ES-2re test dummy, as well as for the new 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 three separate injury criteria for chest: TTI for the SID-H3, chest deflection and lower spine acceleration for the ES-2re, and lower spine acceleration for the SID-IIs. For the proposed pole test, the agency is proposing an injury criteria for chest deflection of 42 mm for the ES-2re and for lower spine acceleration of 82 g's for the ES-2re 50th percentile male test dummy and for the SID-IIs 5th percentile female test dummy.

Abdomen – For the proposed pole test, the agency is proposing an abdominal force limit of 2.8 kN for the ES-2re 50th percentile test dummy.

Pelvis – For the proposed pole test, the agency is proposing a pelvic force limit of 6.0 kN for the ES-2re 50th percentile male test dummy and 5.3 kN for the SID-IIs 5th percentile female test dummy.

B. Injury Criteria for Test Dummies Used

(1) ES-2re Injury Criteria

The proposed 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 proposed 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 proposed 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 proposing use of the ES-2re.

It should be noted that the ES-2re has a rib module design that only allows rib deflection potentiometer motion in lateral direction. Because of this, the deflection measurement is lower in oblique impacts. We performed a series of pendulum tests to determine the sensitivity of the ES-2re dummy responses to directional impact[1]. The results show that the chest deflection apparently corresponds to the lateral component of the applied force[2].

Head: NHTSA is proposing to require passenger cars and LTVs to limit the HIC to 1,000 (measured in a 36 millisecond time interval) when the ES-2re dummy is used in the proposed 20 mph oblique vehicle-to-pole test. This measure has been chosen primarily for two reasons. First, the HIC_{36} 1000 criterion is consistent with the optional pole test designed to afford head protection under FMVSS No. 201. Second, this measure is consistent with the requirement in the European side impact standard for the EuroSID-1. Thus, the HIC_{36}-1000 criterion provides a measure with which the agency already has experience.

---

[1] Draft technical Report, "Design, Development and Evaluation of the ES-2re Side Crash Test Dummy," August 2003.

[2] The actual lateral chest deflection (26.0 mm) in the 4.3 m/s lateral impact test was about 7% less than the deflection calculated (27.97 mm) based on the lateral component of the applied force.

Thorax (Chest): NHTSA has proposed two criteria to measure thoracic injury when using the ES-2re. First, chest deflection may be no greater than 42 mm (reflecting a 48 percent risk of an AIS 3+ injury). Second, chest resultant lower spine acceleration may be no greater than 82 g's (reflecting a 50 percent risk of an AIS 3+ injury).

Chest deflection has been shown to be the best predictor of thoracic injuries in low-speed crashes. We believe it to be a more biofidelic chest measure than TTI(d).[3] The spinal acceleration criterion was added because NHTSA believes that there may be injurious loading conditions that are not picked up by rib deflections, and spinal accelerations have been found to be very good predictors because they represent the overall load on the thorax. Lower spine acceleration is a good indicator of thoracic injuries at high speeds, and is a measure that is less sensitive to direction of impact. Consequently, in concert, the two thoracic criteria have been shown to enhance injury detection and are expected to provide an additional safety benefit for chest injuries as compared to the current standard.[4]

The proposed pole test requires a chest deflection limit of 42 mm, however the agency is requesting comments on the range of 38 to 44 mm. NHTSA reanalyzed the Eppinger data set (see footnote immediately above) and the injury risk curve versus TTI(d) and estimated that a rib

---

[3]TTI(d), a chest acceleration-based criteria, when combined with anthropometric data, was developed by NHTSA (Eppinger, R. H., Marcus, J. H., Morgan, R. M., (1984), "Development of Dummy and Injury Index for NHTSA's Thoracic Side Impact Protection Research Program," SAE Paper No. 840885, Government/Industry Meeting and Exposition, Washington, D.C.; Morgan, R.M., Marcus, J. H., Eppinger, R. H., (1986), "Side Impact – The Biofidelity of NHTSA's Proposed ATD and Efficacy of TTI," SAE Paper No. 861877, 30th Stapp Car Crash Conference) and is included in the FMVSS No. 214 side impact protection standard.

[4]Kuppa, S, Eppinger, R, Maltese, M, Naik, R, Pintar, F, Yoganandan, N, Saul, R, McFadden, J, "Assessment of Thoracic Injury Criteria for Side Impact," Proceedings of the 2000 Conference of the International Research Council on Biomechanics and Injury (IRCOBI) (2000).

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 ($p<0.05$).)

Resultant spine acceleration would not be limited to lateral acceleration. The upper and lower spine of the ES-2re is instrumented with tri-axial accelerometers (x, y, and z direction corresponding to anterior-posterior, lateral medial, and inferior-superior). In purely lateral loading, one would expect only lateral (y) accelerations. Moreover, due to constraints built into their designs, the dummies exhibit predominantly y (lateral) acceleration due to lateral loading. In side impact sled tests at the Medical College of Wisconsin (MCW), the dummy's T12 lateral (y) accelerations were almost the same as the resultant acceleration $[(x^2+y^2+z^2)^{1/2}]$, since x and z accelerations are small. However, due to the complex response of humans, vehicle occupants experience x, y, z accelerations even in pure lateral loading. 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. 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

$$p(AIS3+) = \frac{1}{1+e^{(2.3743-0.054511*peak\ rib.\ defl.)}}$$

$$p(AIS4+) = \frac{1}{1+e^{(3.6459-0.054511*peak\ rib.\ defl.)}}$$

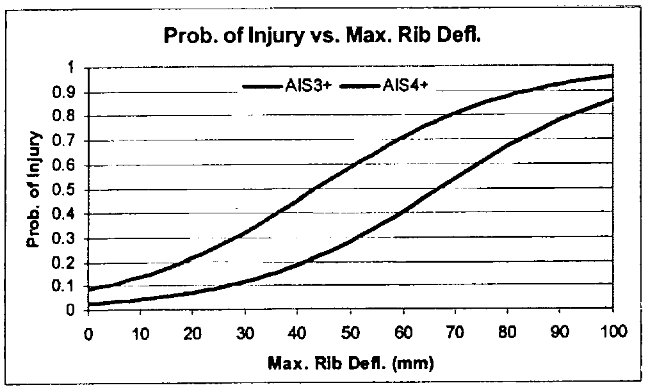


Figure III-1. Probability of AIS 3+ and AIS 4+ injury as a function of maximum ES2 rib deflection

Regarding the lower spine acceleration, the chest injury probability curve for AIS 3+ injuries is available below:

$$p(AIS3+) = \frac{1}{1+e^{(2.2008-0.0268*(peak\ lower\ spine\ accl.)}}$$

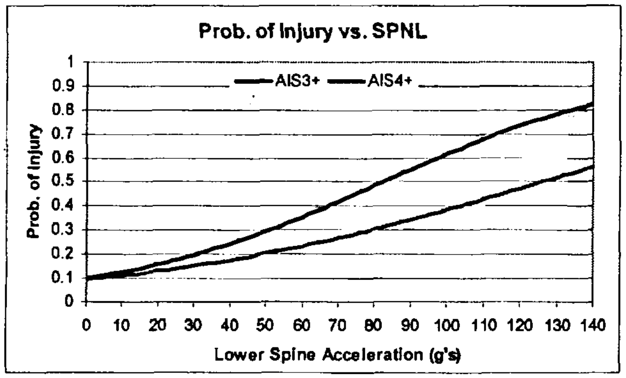


Figure III-2. Probability of AIS 3+ and AIS 4+ Injury as a function of ES-2re Lower Spine Accelerations

Abdomen: The ES-2re dummy offers abdominal injury assessment capability, a feature that is not incorporated in the SID-H3 dummy. The agency is proposing an abdominal injury criterion of 2.8 kN (50 percent risk of AIS3+ injuries). The abdominal injury criterion was developed using cadaver drop test data from Walfisch, et al. (1980)[5]. Analysis of this data indicated that applied force was the best predictor of abdominal injury. An applied force of 2.8 kN corresponds to a 50 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 2.8 kN corresponds to a 50 percent risk of AIS 3+ injury.

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

[5] 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.

percent and 18 percent of all AIS 3+ injuries are to the abdomen of restrained drivers.[6] 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 noted earlier, the abdominal load injury criterion has been applied to the European side impact regulation EU 96/27/EC, as well as the EuroNCAP Program. The criterion in those programs is 2.5 kN.

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 and was found to have 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 curves are shown in Figure III-3.

[6] 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).

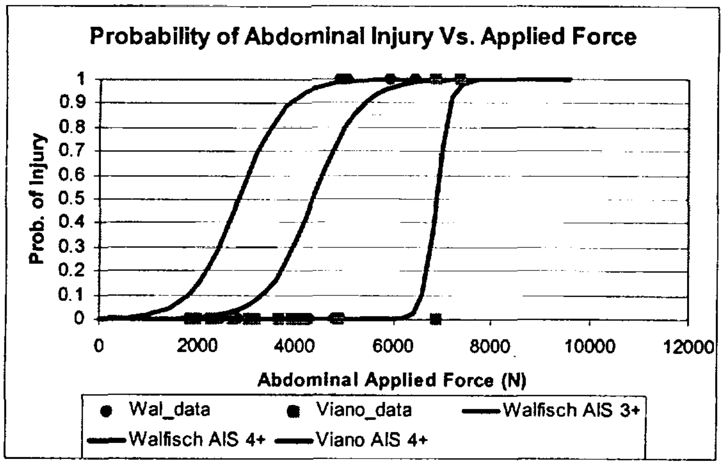


Figure III-3. Probability of AIS 3+ and AIS 4+ abdominal injury based on Walfisch (1980) and Viano (1989).

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

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

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

Pelvis: For the ES-2re, NHTSA is proposing 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).[7] 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

$$P(\text{AIS } 3+) = 1/(1 + e^{6.403 - 0.00163*F})$$

$$P(\text{AIS } 4+) = 1/(1 + e^{7.5969 - 0.0011*F})$$

(2) SID-H3 Injury Criteria

Head: The head injury criterion and the injury probability for each injury level are the same as those of the ES-2re.

Chest: The chest injury probability equations for AIS 3+ and 4+ are shown in Table III-4, and the corresponding risk curves are shown in Figure III-4.

Table III-4
Chest Injury Probability Curves for SID-H3

$$p(AIS3+) = \frac{1}{1+e^{6.4156-0.0796*TTI}}$$

$$p(AIS4+) = \frac{1}{1+e^{7.2383-0.0796*TTI}}$$

[7] 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.

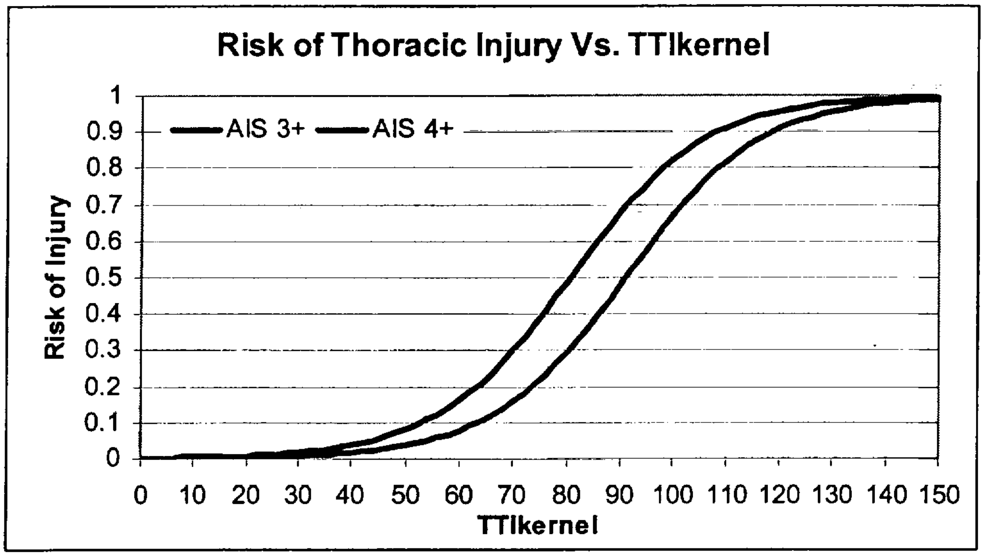


Figure III-4. Probability of Thoracic Injury Vs. TTI

Pelvis: The probability of a pelvis fracture as a function of a pelvic acceleration is used to determine the injury risk. The pelvic fracture risk curve would produce a level of risk that is similar to AIS 2+ injuries. The equation for the pelvic fracture risk curve is shown in Table III-5.

Table III-5
Pelvic Injury Probability Curves for SID-H3

$$p(AIS2+) = \frac{1}{1 + e^{(4.1633 - 0.01814 * peak\ pelvic\ acceleration\ (g's))}}$$

(3) SID-IIs Injury Criteria

Injury criteria are being proposed 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 the SID-IIs FRG[8]," which has been placed in the Docket for the FMVSS No. 214 NPRM.

Head: The head injury criterion (HIC) shall not exceed 1000 in 36 ms, when calculated in accordance with the equation specified in S7 of FMVSS No. 201.

Thorax (Chest): NHTSA is proposing 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 would 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. 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

---

[8] The SID-IIs with Floating Rib Guide (FRG) hardware. See "Biofidelity Assessment of the SID IIs FRG Dummy," a copy of which has been placed in the docket.

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.

Similar to the ES-2re dummy, the SID-IIs appears to have a degree of directional sensitivity in oblique loading conditions. Moreover, tests comparing the SID-IIsFRG to the SID-IIs without FRG (baseline) show that the dummy with the FRG recorded rib deflections up to 20 percent lower than the baseline SID-IIs. The injury probability equations are shown in Table III-6.

Table III-6
Chest Injury Probability Curves for SID-IIs

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

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

$$p(AIS3+) = \frac{1}{1+e^{(3.8231-0.0536*lowerSpineAccel.)}}$$

Pelvis: The pelvic injury criteria of 5.3 kN for the SID-IIs were developed using the cadaver test data from Bouquet et al. (1998) by scaling the normalized force to that of a 5^{th} percentile female using the scale factor $(48/75)^{0.66}$. 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

$$p(AIS3+) = \frac{1}{1 + e^{(5.7278 - 0.00109 * (iliac + acetab.\ force))}}$$

$$p(AIS4+) = \frac{1}{1 + e^{(8.3364 - 0.00109 * (iliac + acetab.\ force))}}$$

IV. TEST DATA AND ANALYSIS OF POLE TEST DATA

This chapter presents test data available to the agency on the various static and dynamic test procedures mandated by the proposed pole test.

As part of the agency's research effort, a series of proposed oblique pole and FMVSS No. 201 optional pole tests were performed. The oblique pole test is similar to the FMVSS No. 201 optional pole test with modifications relating to the angle, speed and also the test dummies used in the test. In addition, a series of oblique pole tests with the ES-2re 50th percentile test dummy positioned according to the FMVSS No. 214 seating procedure were also performed.

A. Pole. The proposed oblique pole has the same specifications as the pole used in the FMVSS No. 201-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 Standard No. 201 test, the impact reference line is vertical and passes through a point in the lateral direction through the center of gravity (cg) of the head of the dummy located in the front outboard seating position. The FMVSS No. 201

procedures specify positioning the dummy, and the vehicle seat, as in Standard No. 214, but if the rear surface of the dummy's head is less than 50 mm (2 inches) forward of the front edge of the B-pillar, the seat back angle and seat are adjusted forward to achieve that 2-inch clearance. In the procedures 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 proposed oblique pole test, the dummy and the vehicle seat are positioned as in FMVSS 214 (i.e., mid-track). Under FMVSS No. 201 procedures and the proposed oblique pole test, 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 proposed 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 as specified in FMVSS No. 201. 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 this proposal, 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 are tested at a vehicle delta-V of 20 mph for the oblique pole tests and 18 mph for the FMVSS No. 201 optional 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 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 to incorporate an oblique impact in a side impact protection standard. The agency tentatively concludes that the proposed oblique pole test would enhance safety because it is more representative of real-world side impact pole crashes. Frontal oblique crashes, i.e., at a principal direction of force (PDOF) 0 to 84 degrees clockwise or counter clockwise from 12 o'clock, account for about 68 percent of the seriously injured (MAIS 3+) occupants in narrow object crashes, while crashes with 90 degree approaches account for approximately 16 percent of the seriously injured (MAIS 3+) occupants. There is not a particular angle of approach that is predominant in nearside narrow object crashes, while the cumulative distribution has a mean of a 60-degree impact angle.

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 percentile male test dummy and the vehicle seat positioned as in the FMVSS No. 214 seating procedure.[1,2]

(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. 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

[1] The NPRM also asks for comments on the FMVSS No. 201 seating procedures, that would be used instead of the FMVSS No. 214 seating procedure, if the latter is not adopted. Under the FMVSS No. 201 seating procedures, the dummy's head would be positioned such that the point at the intersection of the rear surface of its head and a horizontal line parallel to the longitudinal centerline of the vehicle passing through the head's center of gravity is at least 50 mm (2 inches) forward of the front edge of the B-pillar at that same horizontal location. If needed, the seat back angle would be adjusted, a maximum of 5 degrees, until the 50 mm (2 inches) B-pillar clearance is achieved. If this were not sufficient to produce the desired clearance, the seat would be moved forward to achieve that result.

[2] The agency performed a total of four oblique pole tests with the 1999 Vovo S80 and 2000 Saab (two of each) with the ES-2re. For comparison, the test dummies were positioned with the 214 procedure and also 201 optional pole test procedure. For the Volvo S80 with the 201 procedure, the data show that a HIC of 465, rib deflection of 40.7 mm, lower spine acceleration of 51.3, abdominal force of 1,553 and pubic force of 1,700. With the 214 procedure, the Volvo produced a HIC of 329, rib deflection of 48.6 mm, lower spine acceleration of 51.2, abdominal force of 1,547 and pubic force of 1,127. For the Saab with the 201 procedure, the data show that a HIC of 243, rib deflection of 49.9 mm, lower spine acceleration of 58.3, abdominal force of 1,382 and pubic force of 2,673. With the 214 procedure, the Volvo produced a HIC of 171, rib deflection of 49.4 mm, lower spine acceleration of 49.0, abdominal force of 1,366 and pubic force of 1,733.

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.

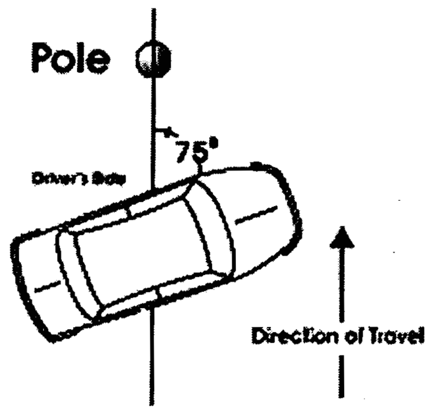


Figure IV-1. Illustration of Oblique Pole Impact

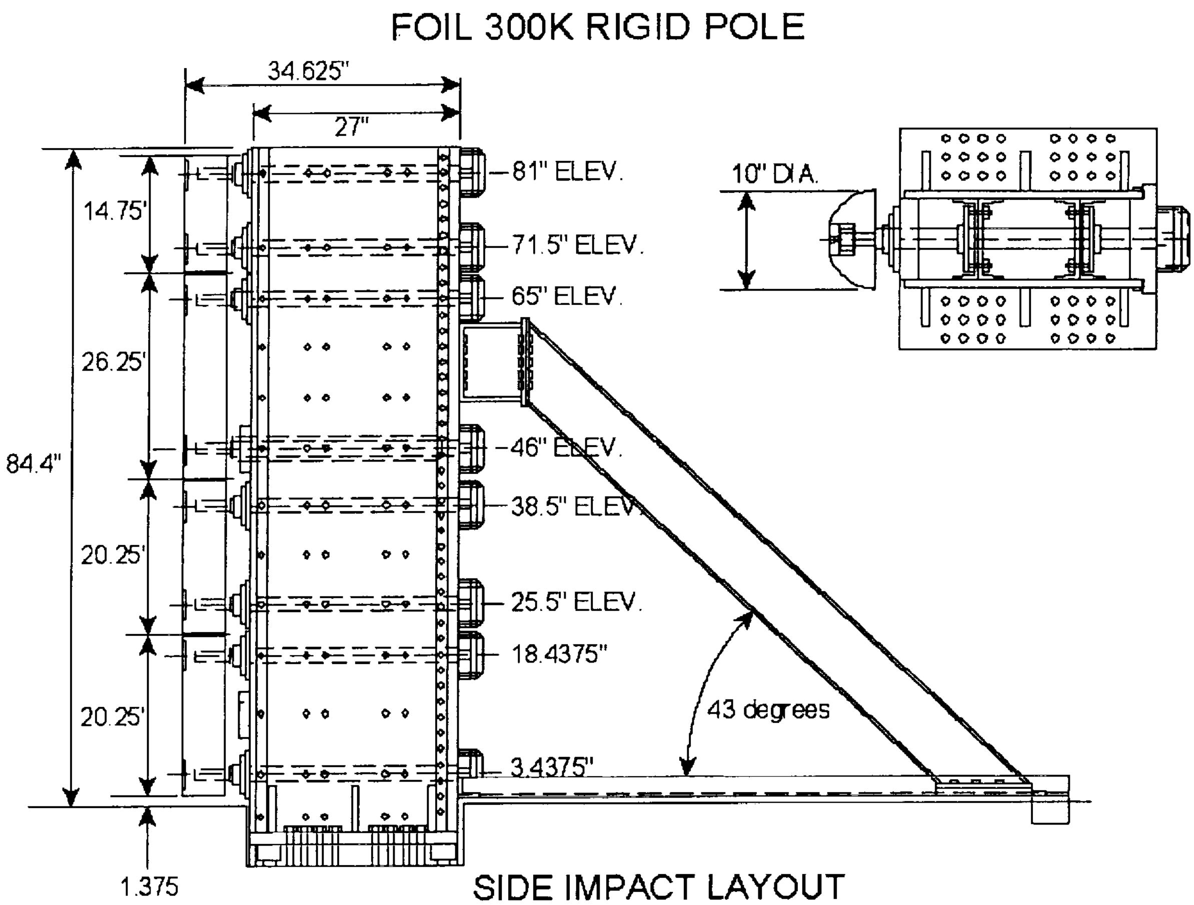


Figure IV-2. Dimension and Construction of Pole

B. Test Dummies

1. <u>ES-2re 50th Percentile Male Crash 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,"[3] 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.

[3] 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.[4] The instrumentation locations for the ES-2 are shown in Figure IV-3.

[4] 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.

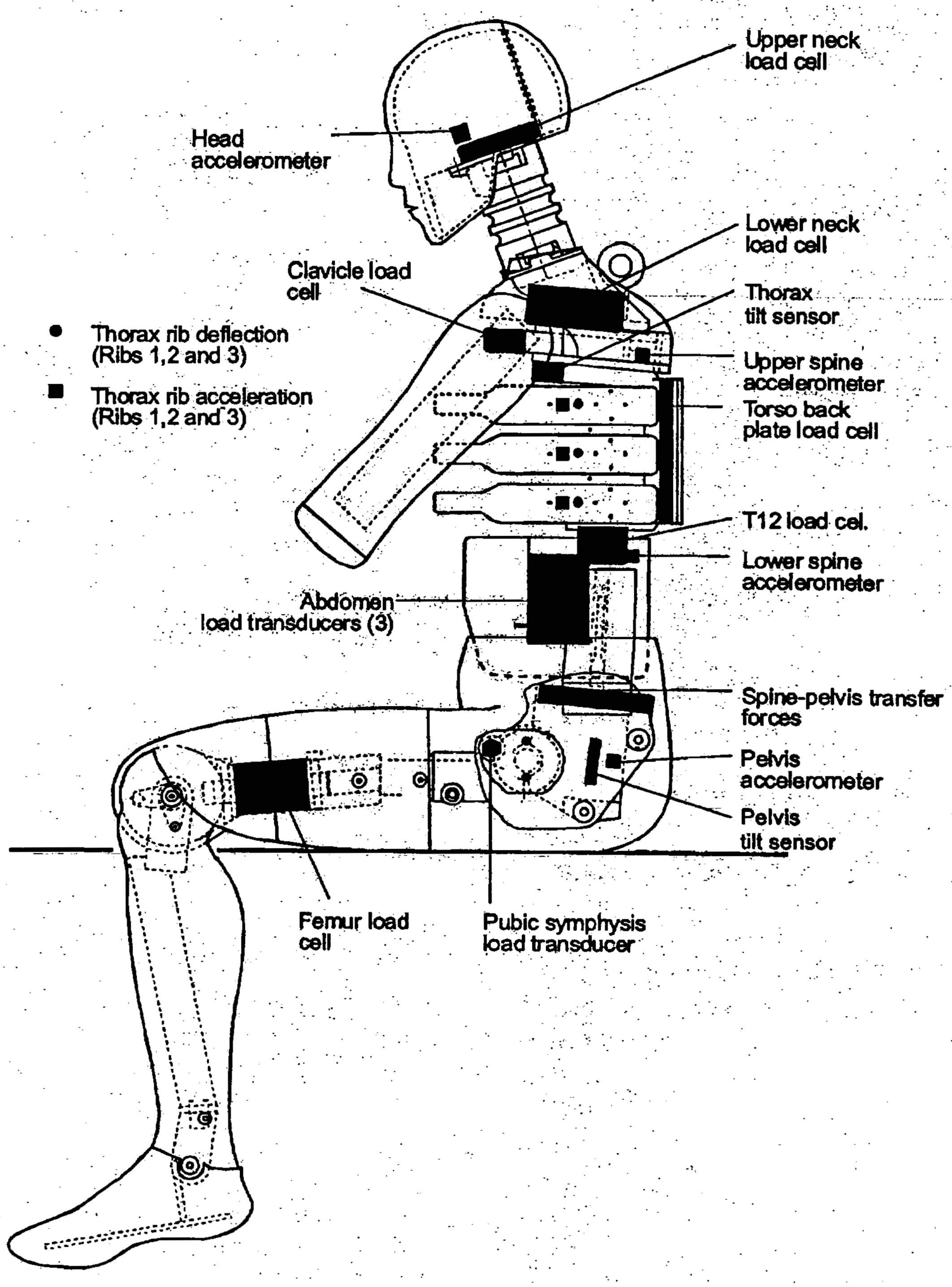


Figure IV-3. Instrumentation Location in ES-2

(2) Biofidelity, Repeatability and Reproducibility. Biofidelity is a measure of how well a test device duplicates the responses of a human being in an impact. The Occupant Safety Research Partnership and Transport Canada conducted biomechanical testing on the ES-2 dummy. Byrnes, et al., "ES-2 Dummy Biomechanical Responses," 2002, Stapp Car Crash Journal, Vol. 46, p. 353. Biomechanical response data were obtained by completing a series of drop, pendulum, and sled tests from the International Organization of Standardization (ISO) Technical Report 9790. Full scale tests were also conducted. The overall dummy biofidelity rating was determined to be "fair," at 4.6, an improvement over the SID and Eurosid-1 (which received ratings classifications of 2.3 and 4.4, respectively).

The agency also used the biofidelity ranking system developed by Rhule et al, "Development of a New Biofidelity Ranking System for Anthropomorphic Test Devices," 2002, Stapp Car Crash Journal, Vol. 46, p. 477. The assessment included the dummy's External Biofidelity (how human-like the dummy loads the vehicle components) and Internal Biofidelity (how human-like the dummy measures injury criteria measurement responses and is calculated for those body regions that have an associated injury criterion). The Overall External and Internal Biofidelity ranks are an average of each of the external and internal body region ranks, respectively. A lower biofidelity rank indicates a more biofidelic dummy. A dummy with an External Biofidelity rank of less than 2.0 responds as much like the cadaver corridors as would another human subject. The ES-2re dummy had an Overall External Biofidelity rank of 2.6, compared to 2.7 for the ES-2 and 3.8 for the SID-H3. Its overall internal biofidelity rank was 1.6.

As part the agency's test dummy development program, the dummy's repeatability and reproducibility were analyzed. The ES-2re dummy's repeatability and reproducibility is based on component tests and a series of sled tests in which it was attempted to control the impact input as well as the test equipment with the goal of minimizing the external efforts on the dummy's response. The peak dummy responses demonstrated excellent repeatability for ES-2re test dummies,[5] in terms of percent cumulative variance (CV). Reproducibility in component tests was established by comparing the average responses of the components of two dummies first against the mean of the calibration specification and then their percent deviations from each other with respect to the mean. The data indicate that the difference in response between the two ES-2re test dummies is in the "excellent" reproducibility range except for maximum pubic force response that is in the "good" range.

2. SID-H3: The SID-H3 is a 50th percentile test dummy designed for side impact tests with the head of a Hybrid III test dummy incorporated on the SID test dummy. The test dummy is used in the optional pole test of FMVSS 201 and also in the agency's New Car Assessment Program in side crashes (Side NCAP). The NPRM is proposing to use the ES-2re and is seeking comments on the SID-H3.

3. 5th Percentile Female 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. The dummy was developed for the purpose of assessing the performance of side air bags in side

[5] See Chapter IX, Draft technical Report, "Design Development and Evaluation of the ES-2re Side Crash Test Dummy," August 2003.

impact tests. It has a mass of 44.5 kg (98 pounds) and a seated height of 790 mm (31.1 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.[6]

(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. Initial testing revealed chest transducer mechanical failures and some ribcage shoulder structural problems. NHTSA's Vehicle Research Test Center modified the dummy's thorax in 2001 to develop floating rib guides ("FRG") to better stabilize the dummy's ribs. It had been visually observed in abdominal-loading sled tests of the SID-IIs that the ribs did not stay in place in some of the tests, which raised a concern that accurate lateral accelerations might not always be measured. NHTSA modified the shoulder rib and rib guide design to remove excessive vertical rib motion.

(2) Biofidelity. The Small Sized Advanced Side Impact Dummy Task Group of the OSRP evaluated the SID-IIs Beta-prototype dummy against its previously established biomechanical response corridors for its critical body regions. (Scherer et al., "SID IIs Beta+-Prototype Dummy Biomechanical Responses," 1998, SAE 983151.) The response corridors were scaled

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

from the 50th percentile adult male corridors defined in an ISO Technical Report 9790 to corridors for a 5th percentile adult female, using established ISO procedures. Tests were performed for the head, neck, shoulder, thorax, abdomen and pelvis regions of the dummy. Testing included drop tests, pendulum impacts and sled tests. The biofidelity of the dummy was calculated using a weighted biomechanical test response procedure developed by the ISO. The overall biofidelity rating of the SID-IIs beta+-prototype was 7.0, which corresponds to an ISO classification of "good."

The agency also used the biofidelity ranking system developed by Rhule et al, 2002, to assess the biofidelity of the SID-IIs with Floating Rib Guide (FRG) hardware. (See "Biofidelity Assessment of the SID IIsFRG dummy," a copy of which has been placed in the docket.) The assessment included the dummy's External Biofidelity and Internal Biofidelity.

The SID-IIsFRG dummy displayed Overall External Biofidelity comparable to that of the ES-2re and original side impact dummies. The SID-IIsFRG provided improved biofidelity over the SID-H3 in all body regions except for the Head/Neck. The Overall Internal Biofidelity ranks of the SID-IIs FRG are all better than those of the other dummies, with the exception of the "without abdomen and with TTI" rank. All body region, Internal Biofidelity ranks were better than, or comparable to, those of the ES-2re, ES-2 original, and SID-H3, except for the Thorax-TTI rank at 2.9. However, the SID-IIsFRG dummy is a deflection-based design and is not expected to rank well in this parameter. Even with an Internal Thorax-TTI rank of 2.9 included in the Overall rank (without abdomen), the SID-IIs Internal Biofidelity rank (1.6) is equivalent to that of the ES-2re (1.6) and better than that of the SID-H3 (1.9). In addition, the SID IIs dummy has the capability of measuring abdominal deflection, which can be correlated to cadaver injury.

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 pole tests were performed at 18 mph and 20 mph at two different impact angles with two different 50th percentile test dummies and a 5th percentile dummy.)

SID-H3 test results: The pole test results from the FMVSS No. 201 optional (perpendicular) pole test and the proposed oblique pole test are shown in Table IV-1.

Table IV-1
NHTSA Pole Test Results with SID-H3 Test Dummy

Test Vehicle	Test (mph)	HPS Type	Head (HIC)[7]	Chest (TTI)	Pelvis (g force)
1999 Volvo S80 4-Dr	18, Per[8]	AC+Th	237	36.0	44.0
1999 BMW 328i 4-Dr	18, Per	ITS+Th	340	47.0	49.0
2001 Lexus GS-300	18, Per	AC+Th	336	51.3	55.7
2001 VW Jetta 4-Dr	18, Per	AC+Th	444	38.0	40.5
2001 Mercedes C240 4-Dr	18, Per	AC+Th	457	78.9	60.2
2002 Ford Explorer 4-Dr	18, Per	AC	183	83.0	48.0
2002 Mercedes 230	18, Per	AC+Th	306	47.0	49.8
2002 Jaguar X-type	18, Per	AC+Th	271	46.6	44.3
2002 Saturn Vue	18, Per	AC	533	53.1	51.5
2003 Cadillac CTS	18, Per	AC+Th	281	45.8	46.6
1999 Nissan Maxima	18, Per	None	9,233	67.0	49.4
2001 Saturn	20, Obl	None	7,493	107.0	55.6
2001 Saturn	18, Per	None	11,071	58.0	53.7
2001 Saturn	18, Per	AC	579	63.0	47.7
2002 Ford Explorer	20, Obl	AC	330	105	81.3
1999 Volvo S80	20, Obl	AC+Th	2,213	57.0	57.6
2000 Saab	20, Obl	Comb	5,155	90.5	79.2

Obl: Oblique pole test; Per: 90 Perpendicular Pole Test; Combo: Combination of head & torso air bag; AC: air curtain; Th: thorax air bag

The results in Table IV-1 show that head air bags are highly effective in preventing head injuries. In the perpendicular pole test, all of the HIC scores measured with deployed head air bags are lower than 580. However, two out of three vehicles with head air bags failed to meet the HIC criterion and had a large failure margin in the oblique pole test. The oblique HIC results indicate that the failed air bags may not be large enough to cover the pole impact area when a SID-H3 dummy is used. In addition, the results from tests using the curtain air bag of the Ford Explorer show that the curtain air bags are not effective in reducing chest injuries in side crashes. For air bags passing the injury criteria, the SID-H3 pole results were further analyzed by body region and air bag type, as shown in Tables IV-2 thru -4.

[7] Scores that are higher than the propose HIC criterion (of 1,000) were not used for HPS characterization since they failed to meet the proposed requirements, unless otherwise stated.
[8] According to the FMVSS No. 201 optional pole test.

Table IV-2
Head Injury Measured with SID-H3

Speed (mph)	Impact Angle	HPS type	Head (Max. HIC of 1,000)		
			Max.	Min.	Avg.
18	Per.	Without	11,071	9,233	10,152
20	Obl.	Without	N/A	N/A	7,493
18	Per.	AC+Th	457	237	333
	Per.	AC	579	183	432
	Per.	ITS+Th	N/A	N/A	340
20	Obl.	AC	N/A	N/A	330
	Obl.	AC+Th	N/A	N/A	2,213
	Obl.	Comb	N/A	N/A	5,155

The test results in Table IV-1 and -2 show that an average HIC of 360 was measured at a vehicle delta-V of 18 mph in a perpendicular pole test with a head protection system. When the HIC results from the 20 mph pole tests are combined with the 18 mph HIC scores of vehicles with a head protection system, the combined average score resulted in a HIC of 358. According to the head injury probability curves, serious injuries would seldom occur at this HIC level (44% probability of no-injury, 35% AIS-1, 14% AIS-2, 5% AIS-3, 1% AIS-4, 0.1% AIS-5 and 0% fatality). In addition, based on these results, it appears that the HIC measurement is not directionally sensitive when the head impacts with a deployed air bag. With regard to repeatability, the HIC scores measured with a curtain & thorax air bag system (AC +Th) produced an average HIC of 333 with a rather small standard deviation of 86.

For the chest injury measurement, the TTI measurements were analyzed by air bag type and impact speed, as shown in Table IV-3.

Table IV-3
Chest Injury Measurement with SID-H3

Speed (mph)	Impact Angle	HPS type	Chest (TTI of 85/90)		
			Max.	Min.	Avg.
18	Per.	Without	67.0	58.0	62.5
20	Obl.	Without	N/A	N/A	107.0
18	Per.	AC+Th	78.9	36.0	49.1
	Per.	AC	83.0	53.1	66.4
	Per.	ITS+Th	N/A	N/A	47.0
20	Obl.	AC	N/A	N/A	105
	Obl.	AC+Th	N/A	N/A	57.0
	Obl.	Comb	N/A	N/A	90.5

The results in Table IV-1 and -3 show that the TTI ranges 83 to 36 for the 18 mph and 105 to 57 for the 20 mph with deployed air bags. With deployed air bags, TTI changes about 57 percent for the 18 mph and 46 percent for the 20 mph pole impacts. The AC+Th results show that the reduction in TTI ranges 21% in the perpendicular to 47% in the oblique pole. When the curtain + thorax was compared to the curtain air bag in the 20 mph oblique pole test, it shows that the baseline TTI was reduced by 46% by the thorax air bag. The results indicated that curtain air bags would not provide any chest protection and that the thorax air bag effectiveness remains relatively unchanged whether it is used with a curtain air bag or not. Without deployed air bags, the maximum baseline TTI measured was 67 in the 18 mph and 107 in the 20 mph pole impacts. These TTI scores show that the maximum TTI score increased by 60% when the impact speed increase from 18 mph to 20 mph. At a TTI of 107, there is a 78% probability of AIS 4+ injuries. For the pelvic injury measurement, the pelvic-g measurements were analyzed by air bag type and impact speed, as shown in Table IV-4.

Table IV-4
Pelvic Injury Measurement with SID-H3

Speed (mph)	Impact Angle	HPS Type	Pelvis (g) (Max. of 130g's)		
			Max.	**Min.**	**Avg.**
18	Per.	Without	53.7	49.4	51.6
20	Obl.	Without	N/A	N/A	55.6
18	Per.	AC+Th	60.2	40.5	48.7
	Per.	AC	51.5	47.7	49.1
	Per.	ITS+Th	N/A	N/A	49.0
20	Obl.	AC	N/A	N/A	81.3
	Obl.	AC+Th	N/A	N/A	57.6
	Obl.	Comb	N/A	N/A	79.2

The results in Table IV-4 show that thorax air bags may not be effective in reducing pelvic injuries. Based on the pelvic acceleration results at a vehicle delta-V of 20 mph, thorax air bags may increase the injury probability when measured with the SID-H3 test dummy. However, regardless of impact speed, the results show that there is a very low probability of serious pelvic injuries in vehicle-to-pole test conditions. Therefore, thorax air bags may have a minimum impact on pelvic injury in vehicle-to-pole crashes. (We note that according to the real world crash data, no serious injuries (AIS -3, -4, -5 & fatal) occurred in vehicle-to-vehicle/others crashes. Thus, based on the real world pelvic fatal injury data and the pelvic acceleration results from the pole sled test, it appears that the current pole test setup may not represent the worst crash scenarios for serious pelvic injuries.)

ES-2 test results: The pole test results from the FMVSS No. 201 optional pole test and the proposed oblique pole test are shown in Table IV-5a.

Table IV-5a.
NHTSA Pole Test Results with ES-2 Test Dummy in 201 Seating Position

Test Vehicle	Test (mph)	HPS Type	Head (HIC)	Chest (mm, Rib-Deflection.)[9]	Abdomen (Force)	Pubic (Force)
2000 Saab	20, Obl	Combo	243	49.9 mm	1,382 N	-2,673 N
2000 Saab	18, Per	Combo	114	37.8 mm	849 N	-1,733 N
1999 Volvo S80	20, Obl	AC+Th	465	40.7 mm	1,553 N	-1,700 N
1999 Volvo S80	18, Per	AC+Th	244	41.5 mm	1,217 N	-1,166 N
1999 Nissan Maxima	20, Obl	None	11,983	41.5 mm	2,150 N	-2,548 N
1999 Nissan Maxima	20, Obl	None	15,591	43.7 mm	2,014 N	-2,495 N
1999 Nissan Maxima	18, Per	None	4,728	45.1 mm	1,758 N	-1,930 N
1999 Nissan Maxima	18, Per	Combo	130	33.3 mm	1,450 N	-2,080 N
2001 Saturn	20, Obl	None	15,152	49.7 mm	1,622 N	-2,784 N
2001 Saturn	20, Obl	AC	670	52.3 mm	1,224 N	-2,377 N
2001 Saturn	18, Per	None	9,004	44.8 mm	1,022 N	-1,559 N
2001 Saturn	18, Per	AC	435	46.0 mm	1,084 N	-1,917 N
2002 Ford Explorer	18, Per	AC	208	45.9 mm	2,074 N	-1,262 N
1999 Mercury Cougar	18, Per	Combo	313	41.5 mm	859 N	-2,214 N
1999 Ford Windstar	18, Per	Combo	164	31.4 mm	2,352 N	-1,382 N
1999 Nissan Maxima	20, Obl	Combo	5,254	35.7 mm	1,196 N	-2,368 N
2002 Ford Explorer	20, Obl	AC	629	43.0 mm	2,674 N	-2,317N

Table IV-5b.
NHTSA Pole Test Results with ES-2 Test Dummy in 214 Seating Position

Test Vehicle	Test (mph)	HPS Type	Head (HIC)	Chest (mm, Rib-Deflection.)[10]	Abdomen (Force)	Pubic (Force)
1999 Volvo S80	20, Obl	AC+Th	329	48.6 mm	1,547 N	-1,127 N
2000 Saab 9-5	20, Obl	Combo	171	49.4 mm	1,366 N	-1,733 N
2004 Honda Accord	20, Obl	AC+Th	446	30.7 mm	1,437 N	-2,463 N
2004 Toyota Camry	20, Obl	AC+Th	405	43.4 mm	1,165 N	-1,849 N

The ES-2 test results in Table IV-5a also show that head air bags are highly effective in preventing head injuries. However, one out of five air bags failed to meet the HIC criterion in the oblique pole test. The results suggest that the failed combo air bag installed in the 1999

[9] Scores higher than the proposed injury criteria were not used for HPS characterization since they failed to meet the proposed requirements, unless otherwise stated.
[10] Scores higher than the proposed injury criteria were not used for HPS characterization since they failed to meet the proposed requirements, unless otherwise stated.

Nissan Maxima may not be wide enough to restrain the head in the oblique pole test. For air bags passing the injury criteria, the ES-2 pole test results were further analyzed by body region and air bag type, as shown in Tables IV-6 thru -9.

Table IV-6
Head Injury Measurement with ES-2
(With the 201 seating procedure)

Speed (mph)	**Impact Angle**	**HPS Type**	**Head (Max. HIC of 1,000)**		
			Max.	**Min.**	**Avg.**
18	Per.	Without	9,004	4,728	6,866
20	Obl.	Without	15,592	11,983	14,242
18	Per.	AC+Th	*	*	244
	Per.	AC	435	208	321
	Per.	Combo	313	114	180
20	Obl.	AC+Th	*	*	465
	Obl.	Combo	*	*	243
	Obl.	AC	670	629	650

* No data. HIC scores higher than 1,000 were excluded.

For the chest injury measurement, the chest deflection measurements were analyzed by air bag type and impact speed, as shown in Table IV-7.

Table IV-7
Chest Injury Measurement with ES-2
(With the 201 seating procedure)

Speed (mph)	**Impact Angle**	**HPS Type**	**Chest (Max. Rib-Def. Of 42 mm)[11]**		
			Max.	**Min.**	**Avg.**
18	Per.	Without	45.1	44.8	45
20	Obl.	Without	49.7	41.5	46
18	Per.	AC+Th	*	*	41.5
	Per.	Combo	41.5	31.4	36
20	Obl.	AC+Th	*	*	40.7
	Obl.	Combo	*	35.7	35.7
	Obl.	AC	*	43.0#	43.0#

* No data. #Failed

[11] Scores higher than the proposed injury criteria were not used for HPS characterization since they failed to meet the proposed 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 in the representative of the vehicle fleet and therefore not used in the calculations.

The results in Table IV-5 and -7 show that the baseline chest deflection (i.e., without deployed air bags) was an average of 45 mm for the 18 mph and 46 mm for the 20 mph. Without deployed air bags, the maximum baseline deflection measured was 45.1 mm in the 18 mph and 49.7 mm in the 20 mph pole impacts. These chest deflection scores (of the ES-2) show that the maximum deflection increased by 11% when the impact speed increase from 18 mph to 20 mph. At a chest deflection of 49.7 mm, there is a 28% probability of AIS 4+ injuries. With deployed air bags, the deflection ranges from 31.4 mm to 41.5 mm for the 18 mph and 35.7 mm to 42.0 mm to for the 20 mph pole tests, respectively. In addition to the chest deflection criterion, the maximum resultant lower spine acceleration performance limit of 82 g's is required by the proposed oblique pole test. The measured lower spine acceleration scores are shown in Table IV-8 for the 20 mph oblique pole tests.

Table IV-8
Resultant Lower Spine Acceleration in 20 MPH Oblique Pole with ES-2
(With the 201 seating Procedure)

Test Vehicle	NHTSA Test No.	HPS Type	Resultant lower spine acceleration (g) (Max. 82 g)
2000 Saab	V4378	Combo	58.3
1999 Volvo S80	V4389	AC+Th	51.3
1999 Nissan Maxima	V4285	None	83.4
1999 Nissan Maxima	V4365	None	84.6
2001 Saturn	V4246	None	70.2
2001 Saturn	V4313	AC	78.2
1999 Nissan Maxima	V4284	Combo	45.1
2002 Ford Explorer	V4471	AC	98.4

The results in Table IV-8 show that an average acceleration of 79g was measured without deployed air bags. With deployed air bags, the lower spine acceleration was reduced by 16 % from 79g to 66g. Regarding air bag type, the results show that the combo air bags resulted in an average acceleration of 51.7g, whereas the single thorax air bag resulted in an acceleration of 51.3g. When the performance of the combo and thorax side air bags were compared, it appears that the combo air bags are similar to the thorax side air bag in terms of lower spine acceleration.

For the abdominal injury measurement, the abdominal force measurements were analyzed by air bag type and impact speed, as shown in Table IV-9.

Table IV-9
Abdomen Injury Measurement with ES-2
(With the 201 seating procedure)

Speed (mph)	Impact Angle	HPS Type	Abdomen (Max. Force of 2.8 kN)		
			Max	Min.	Avg.
18	Per.	Without	1.758	1.022	1.390
20	Obl.	Without	2.150	1.622	1.928
18	Per.	AC+Th	*	*	1.217
	Per.	AC	2.074	1.084	1.584
	Per.	Combo	2.352	0.849	1.378
20	Obl.	AC+Th	*	*	1.553
	Obl.	Combo	1.382	1.192	1.287
	Obl.	AC	*	*	1.224

* No data

The results in Table IV-9 show that none of the baseline vehicles failed the proposed injury criterion of 2.8 kN abdomen force.

For the pelvic injury measurement, similar to the abdominal force measurement, the pelvic-g measurements were analyzed by air bag type and impact speed, as shown in Table IV-10.

Table IV-10
Pelvis Injury Measurement with ES-2
(With the 201 seating procedure)

Speed (mph)	Impact Angle	HPS Type	Pelvis (Min. pubic Force of 6.0 kN).		
			Max.	Min.	Avg.
18	Per.	Without	-1.930	-1.559	-1.745
20	Obl.	Without	-2.784	-2.495	-2.609
18	Per.	AC+Th	*	*	-1.166
	Per.	AC	-1.262	-1.917	-1.590
	Per.	Combo	-2.214	-1.382	-1.852
20	Obl.	AC+Th	*	*	-1.700
	Obl.	Combo	-2.673	-2.368	-2.521
	Obl.	AC	-2.377	-2.317	-2.347

The results in Table IV-10 show that none of the baseline vehicles failed the proposed injury criterion of 6.0 kN. An average pelvic force of 2.6 kN was measured without deployed air bags in the pole tests.

SID-IIs test results: The SID-IIs measurements resulting from the proposed oblique pole test are shown in Table IV-11.

Table IV-11
Oblique (75-degree) Pole Tests with SID-IIs FRG.

Test Vehicle	NHTSA Test #	Air bag / Restraint	HIC	Thorax Rib Deflection[12] (mm)	Lower Spine Acceleration (g) [13]	Abdomen Deflection (mm)	Pelvis (g)
2002 Explorer	V4564	No deployment*	14,362	No data	97.3	No data	84.5
2002 Explorer	V4563	Head curtain	4,595	37.4	101.2	46.8	85.6
2000 Saab 9-5	V4565	Head/thorax combo	2,233	31.7	66.9	29.5	65.9
2003 Toyota Camry	V4570	No deployment*	8,706	36.4	78.3	42.1	71.6
2003 Toyota Camry	V4580	Head Curtain and thorax	512	33.8	70.1	42.3	80.0

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

* The HPS did not deploy.

The results in Table IV-10 show that the majority of the vehicles tested (2 out of 3 models tested) failed to deploy air bag with the 5th percentile test dummy. With the location of the sensor is found in the B-pillar, we suspected that since the dummy is positioned in the foremost seating position, the alignment of the pole was more forward such that the sensor could not detect the crash impulse. When the sensor of the Toyota Camry was manually triggered in its second test (as indicated by NHTSA test No. V4580), the deployed head curtain head air resulted in a low HIC score. The SID-IIs pole test results were further analyzed by body region, as shown in Tables IV-12 thru -13.

Table IV-12
Head and Pelvic Injury Measures with SID-IIs FRG

Speed (mph)	Impact Angle	HPS	Head (Max. HIC of 1,000)			Pelvis (Max. g of 100g's)		
			Max.	Min.	Avg.	Max.	Min	Avg.
20	75	Without	14,362	8,705	11,533	*	*	79
20	75	With	*	*	512	85.6	65.7	77

* No data

Head. A HIC_{36} of 1,000 was used as the injury criterion. This injury criterion is same as for the 50th percentile test dummies.

Pelvis. The results in Table IV-11 show that the baseline pelvic acceleration was lower than. In addition, the pelvic acceleration data for the deployed air bag case shows that the pelvic acceleration was reduced by about 3% with air bags deployed. It indicates that reduction in pelvic acceleration would be insignificant when a 5th percentile test dummy is used.

Chest: The rib deflection and lower spine acceleration measured are shown in Table IV-13.

Table IV-13
Chest Injuries Measured with SID-IIs

Speed (mph)	Impact Angle	HPS	Thorax Rib Deflection			Lower Spine Acceleration (g) (Max. of 85g)		
			Max.	Min.	Avg.	Max.	Min.	Avg.
20	75	Without	*	*	36	97.3	78.3	87.8
20	75	with	37	32	34	101.2	70.1	79.4

* No data

The results in Table IV-13 show that air bags reduced the rib deflection by 6% from 36 mm to 34 mm. In addition, the lower spine acceleration was reduced by 10% from 87.8g to 79.4g.

D. SID-H3 vs. ES-2 Response

(1) Head. The pole test results show that both the ES-2re and the SID-H3 would yield comparable benefits in head protection.

(2) Chest. Both the ES-2re and SID-H3 have similar thorax constructions. Both have an exterior rib structure and internal energy-absorbing dampers, and both offer acceleration measurements at the struck-side rib and spine. The ES-2re offers additional instrumentation to measure the thoracic deflection of its thoracic ribs.

Directional Impact Sensitivity: As part of the directional impact sensitivity study of the ES-2re, a series of twelve pendulum tests were conducted on the ES-2re. Six tests were conducted at 4.3 m/s, and another six at 6.5 m/s. At each speed, three tests were conducted at a 90-degree impact angle and the other three at 60-degree lateral from the midsagittal plane.[14] The dummy's arm was positioned such that the probe directly impacted the ribs. The probe was aligned so that its trajectory passed through the c.g. of the thorax. The alignment through the c.g. was pre-determined to be the orientation where no torso rotation resulted from an impact.[15] The rib deflection from each of the three thoracic ribs were averaged and then averaged for the three repeat tests. The displacements in the 60-degree oblique pendulum tests were about 6 to 10 mm less than in the 90-degree lateral tests. The average peak rib displacement ratio for oblique to lateral impacts was 0.81 and 0.80 for 4.3 m/s and 6.7 m/s impacts, respectively, as shown in Table IV-14.

Table IV-14
Average Rib Displacement Comparison

Test Dummy	**Impact Speed (m/s)**	**Displacement (mm, filter with FIR 100)**		**Average Peak Rib Displacement Ratio: Oblique/Lateral**
		Impact Angle (degree)		
		90	60	
ES-2re	4.3	32.3	26.0	0.81
	6.7	46.8	37.4	0.80

The results from the pendulum tests show that the ES-2re measured reduced rib deflections in 60-degree oblique lateral impacts when compared to 90-degree lateral impacts. The reduction ratios are 0.81 and 0.80 for the low-speed and high-speed pendulum impacts, respectively. The ES-2re has a rib module designed that only allows rib deflection potentiometer motion in the mid-colonial plane. Because of this, the deflection measurement is lower in oblique impacts. The reduction ratio of approximately 0.81 is similar to the cosine of the angle of loading (cosine 30° = 0.866) and apparently corresponding to the lateral component of the applied force. The

[14] See VIII, Draft Technical Report, "Design Development and Evaluation of the ES-2re Side Crash Test Dummy," August 2003.
[15] See Appendix A, Draft Technical Report, "Design Development and Evaluation of the ES-2re Side Crash Test Dummy," August 2003.

reduction ratios show that if the test were performed at an impact angle of 75-degrees, the resulted deflection would be 97% of the chest deflection result from the 90-degree lateral impact at a given impact speed (cosine 15° = 0.97).

In the oblique pole test with 201 seating procedures, an average TTI of 107 and average chest deflection of 46 mm were measured with the SID-H3 and the ES-2, respectively at a vehicle delta-V of 20 mph. The measurements show a considerable discrepancy in terms of injury probability at a given delta-V. For example, according to the baseline TTI of 107, there is a 78% probability of AIS 4+ injuries. However, according to the chest deflection of 46 mm, there is a 24% probability of AIS 4+ injuries. To some extent, directional impact sensitivity of the ES-2 chest contributed to the difference in injury risk (78% vs. 24%). However, since the pendulum test results show that the ES-2 chest deflection would correspond to about 97% of the applied force, we believe that the direction sensitivity did not substantially influence the difference.

<u>Relative Dummy Chest Position</u>: Regarding the dummy chest position, the SID-H3 has a more upright posture at the outset of the test when compared to the ES-2. The SID-H3 dummy starts out sitting in a stiffer, more upright position than the ES-2re, and is situated more forward in the vehicle than the ES-2re and in a position more likely to be in contact with deformed vehicle structure (by the pole). A comparison of the head and thorax of the SID-H3 and ES-2 dummies are shown in Figure IV-4.

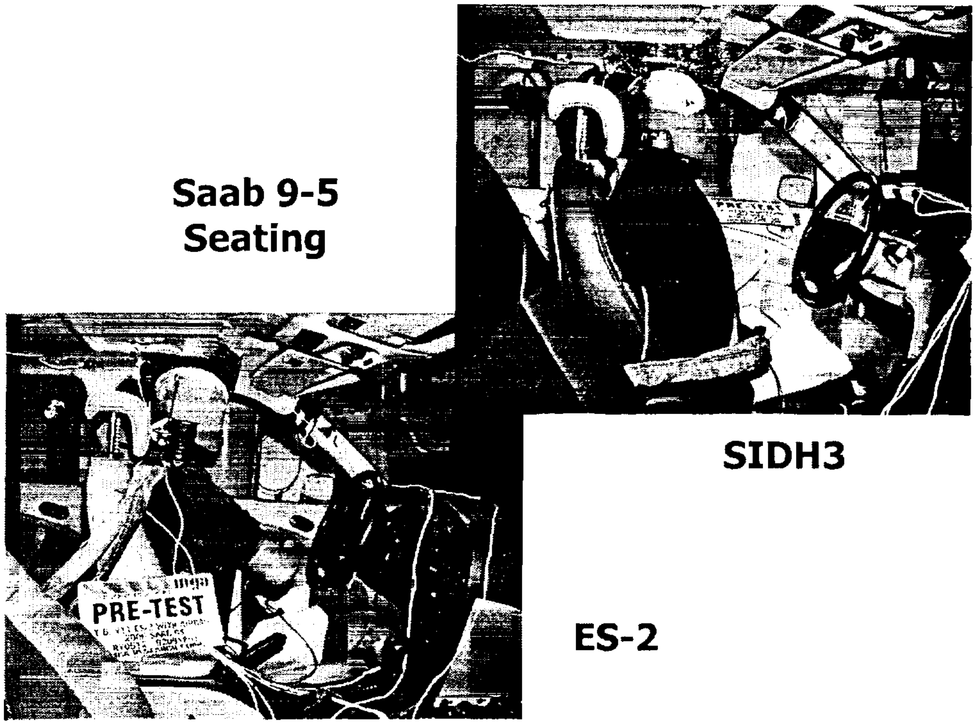


Figure IV-4 Relative Position of Head and Thorax of SID-H3 and ES-2 in Volvo S80[16]

The real world crash data in Chapter V show that serious chest injuries do occur when a vehicle impacts with a pole or tree in side crashes at a delta-V range of 12-25 mph. According to the target population, 231 out of 298 thorax injuries were MAIS 4+ injuries (i.e., 78%) and all of the 298 were MAIS 3+ at a vehicle delta-V range of 12-25 mph. The baseline TTI of 107 measured at a vehicle delta-V of 20 mph with the SID-H3 shows that there is a 78% probability of AIS 4+ chest injuries and 89% probability of AIS 3+ at this TTI level. Although the TTI data are limited, the TTI level and the associated injury risk show that the chest of the SID-H3 used in the pole test closely represents serious chest injuries in real world vehicle-to-pole crashes.

[16] Note, regarding the photos, the pictures were taken by a hand-held camera as pre-test photos and are not exactly in the same plane.

In addition to the chest deflection, the lower spine acceleration of the dummy was measured in the 20 mph oblique test with an ES-2re dummy. Both the baseline and deployed accelerations measured at a vehicle delta-V of 20 mph are shown in Table IV-14.

Table IV-14a.
Lower Spine Acceleration Results with ES-2 at 20 mph
Oblique Pole Impact (201 Seating Procedure)

HPS Type	Chest (Lower Spine Acceleration, g)		
	Max.	**Min.**	**Avg.**
Without	84.6	70.2	79
AC+Th	*	*	51.3
Combo	58.3	45.1	51.7
AC	98.4	78.2	88.3

* No data

Table IV-14b.
Lower Spine Acceleration Results with ES-2 at 20 mph
Oblique Pole Impact (214 Seating Procedure)

HPS Type	Chest (Lower Spine Acceleration, g)		
	Max.	**Min.**	**Avg.**
Without	*	*	*
AC+Th	51.2	49.9	50.6
Combo	*	*	49.0
AC	*	*	*

* No data

The baseline data show that there is 48% probability of AIS 3+ injuries at a lower spine acceleration of 79g. Although the use of the lower spine acceleration is better in representing serious chest injuries in real world crashes, when compared to the SID-H3, both the chest deflection and the lower spine acceleration data indicate that the measurements may not represent real world vehicle-to-pole crashes that produce serious chest injuries.

V. BENEFITS

This chapter estimates the potential benefits of the proposed requirements. These benefits would be achieved from the required test and new injury criteria using the pre-MY 2002 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 three different types of test dummies, the SID-H3, the SID-IIs and the EuroSID-2 (ES-2re). Although the 50^{th} percentile dummies (i.e., the SID-H3 and the ES-2) would represent human injury responses during a side crash, the test dummies would respond differently with the same crash input due to difference in kinematic characteristics, seating procedure, and other factors. Therefore, this analysis considers test data from the use of both of these dummies.

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-2002 injury probability as the base. Pole test results from Chapter IV and other test data are used to calculate fatality and injury probability reductions. The injury reduction rate probability is applied to the corresponding target population, which results in fatality or injury reduction benefits.

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 (HPS) performance (referred to "the production HPS" hereafter).

According to weighted 1997-2001 NASS/CDS side impact data, head/face (43%), chest (36%), and abdomen (8%) are the most frequent fatal injuries. 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[1].

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[2] in outboard seating positions in side crashes, as the air bags are designed to deploy from a vehicle's roof rail. The air bags are designed to remain inflated longer than frontal air bags to provide occupant protection during vehicle rollovers[3]. 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

[1] See additional discussion on the target population in the following section.
[2] See section V.F for additional discussion.
[3] The head and side air bag systems may need a separate rollover sensor to deploy the bags in rollover crashes.

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 proposed FMVSS No. 214 pole requirements, curtain bags (AC) (as a stand alone system or combined with a 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 2002 & 2003 Head/Thorax Air bag Systems Availability
(Estimated, Percent by Total Sales of Passenger Cars, SUV, Vans, and Light Trucks)

MY	**Thorax only**	**Curtain (AC) + Thorax (Th)**	**Combo**	**AC only**	**ITS + Thorax**
2002	18.80%	5.75%	7.26%	0.99%	1.24%
2003	10.61%	6.85%	7.48%	3.02%	1.38%

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 proposed 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. The V.E discusses any related issues that would affect the benefit estimates. The V.F shows benefits vs. air bag system. Finally, the V.G discusses head injury risk distribution: Prasad/Hertz and the lognormal.

A. Target Population

A pre-2002 baseline target population is used to estimate benefits since the majority of vehicles were not equipped with head air bags. The NHTSA pole (sled) test results show that these vehicles would not meet the head injury criterion without head protection system (HPS) when they are subjected to the proposed pole test. For the analysis, the target population is defined as occupants who sustained fatal and/or AIS 3 or greater injuries to the head, chest, abdomen and pelvis (i.e., injuries that would be influenced by HPS or thorax air bags) in side crashes[4]. In addition, it was assumed that all vehicles in the fleet for the target population are not equipped with HPS. (In other words, we didn't adjust the target population for the current effectiveness or HPS or thorax air bags since there are so few of them on the road in our 1997-2002 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[5].

As for the HPS upper impact speed limit, the pendulum tests[6] performed by Volvo & Autoliv showed that the curtain air bag started to bottom out into the rigid fixture block at 7 m/s (15.6 mph), at a pressure of about 150 kPa. The report concluded that the pressure level 160 to 220

[4] Unless otherwise stated, the benefits were derived for fatal and AIS 1+.

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

[6] "The inflatable curtain (IC) – A new head protection system in side impacts." 16th International Technical Conference on the Enhanced Safety of Vehicle, Paper Number 98-S8-W-19.

kPa is favorable to cover a pendulum impact velocity up to 15 mph. According to the conversion factor developed[7] by Monk, Gabler and Sullivan, a pendulum speed of 15 mph (as regarded as an occupant impact speed) would result in a vehicle delta-V of 20 mph.

The case study (in Appendix B) shows that an air bag that bottoms out at a vehicle delta-V of 20 mph would produce a HIC of 1,221 in head impacts with a rigid pole. A HIC of 1,221 has a fatality probability of only 0.4 percent. Thus, we believe that a bottomed out air bag will provide fatality benefits at speeds above 20 mph delta-V when striking a rigid pole. On the other hand, the air bag would result in a HIC of 1,099 when head impacts with vehicle interior components at a vehicle delta-V of 30 mph.

Based on the assumption used in the 201 PRE and the results in the case study (as discussed above), we assumed that head air bags are effective for a vehicle delta-V up to 25 mph. In essence this 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 say the 23-25 mph range, depending upon the crash circumstances and what the occupant's head hit. Consequently, a vehicle delta-V range of 12 mph to 25 mph was used for the target population in the analysis.

Target <u>fatalities</u> and MAIS 3-5 injuries are derived from 1997-2001 CDS. For fatalities, the annualized front-outboard occupant fatalities from CDS are adjusted to the 2001 FARS level to overcome the underreporting problem in CDS for fatalities. (See Discussion section for occupants in rear-outboard seating positions.) As for <u>injuries</u>, the annualized target MAIS 3-5 injury population was adjusted to the 2001 GES CDS-equivalent level to get a better national

[7] See discussion in the Final Economic Assessment (FEA) 201 for the conversion factor of 1.3

estimate. For the target population, occupants with heights of at least 65 inches are assumed to be represented by the 50th percentile male dummy (i.e., the SID-H3 or the ES-2), and the remaining occupants are assumed to be represented by the 5^{th} percentile female dummy (i.e., the SID-IIs). Several additional adjustments are made, as discussed below:

1. Children. 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) can 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. Testing child dummies OOP has shown no problem for HPS systems mounted on the roof rail (window curtain and the ITS), but we have seen the potential for injuries with thorax air bags. 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. Out-of-position Occupants. 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 lines and 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.)

<u>3. 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 measurements made with the different test dummies are not "direction sensitive" for the proposed pole test

impact directions of 75 and 90 degrees, except chest deflections measured with the ES-2 test dummy. In other words, the analysis does not distinguish dummy measurements resulting from the 75-degree pole test from measurements resulting from the 90-degree pole test at a given impact speed. For example, 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 proposed 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 proposed 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[8]. 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 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

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

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, two out of seven combo air bags (that were most likely designed for the FMVSS No. 201 optional pole test, (the perpendicular pole impact test) failed to meet the proposed head injury criterion (i.e., HIC of 1,000), whereas, only one out of 18 curtain air bags failed in the NHTSA pole tests. All the failures occurred in oblique pole tests. (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.)

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 proposed impact angles (90 and 75 degrees regardless of lateral delta-V). (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-3 and V-4.

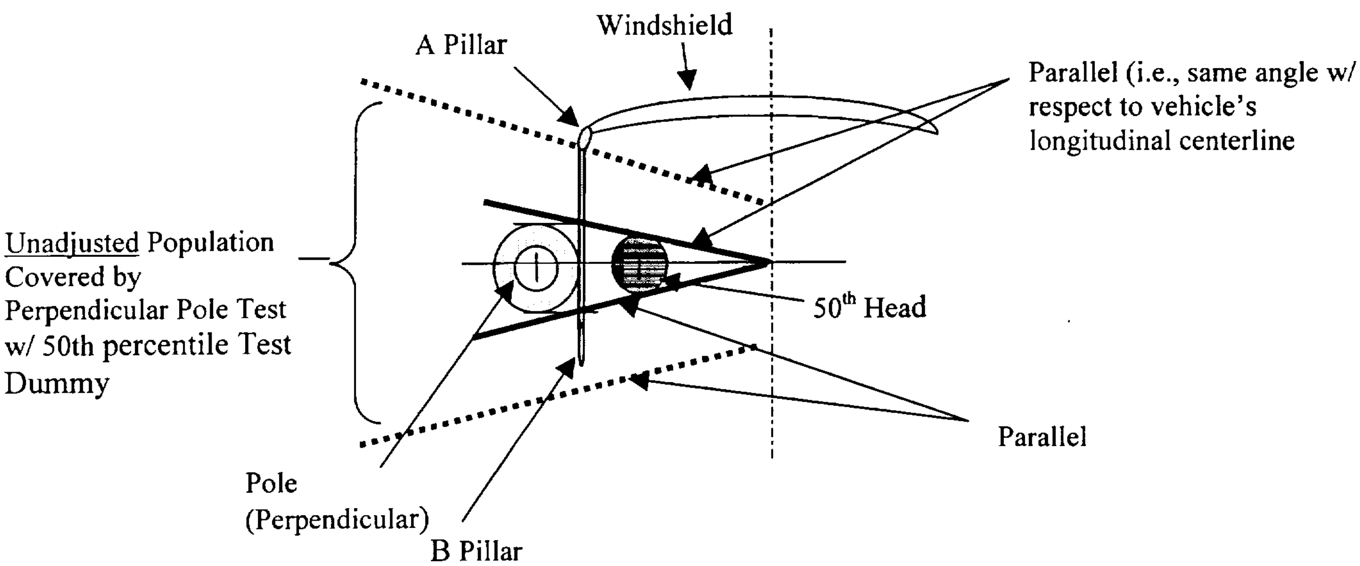


Figure V-1. Overhead View of the Perpendicular Pole and the 50th Percentile Driver Dummy

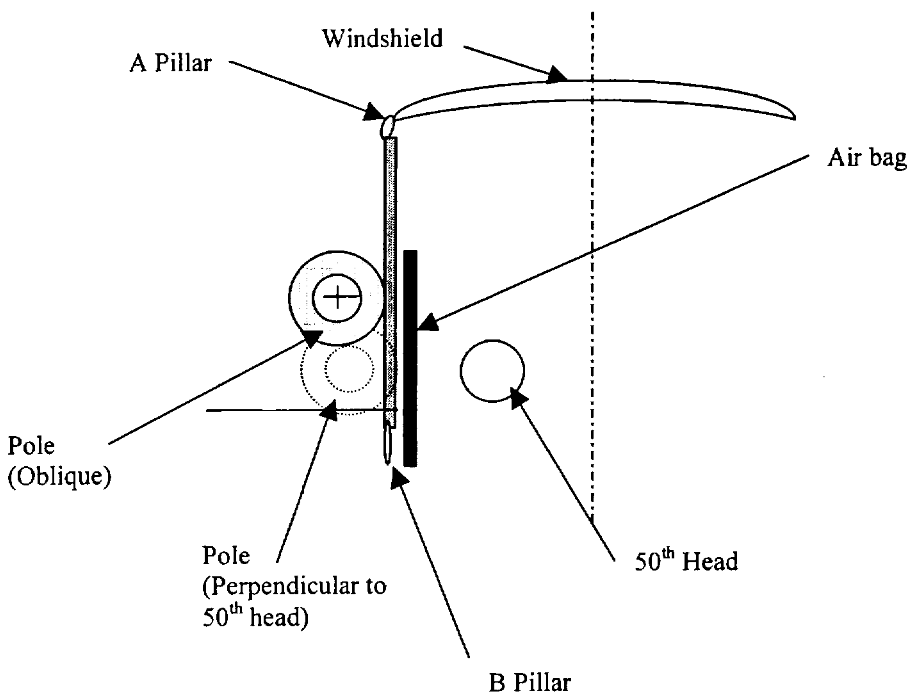


Figure V-2. Illustration of Pole Position: Overhead View of the Perpendicular and Oblique Poles with 50th Dummy

Table V-3
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)[9]	
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

Table V-4
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. $\tan^{-1}[(127 \text{ mm})/(776 \text{ mm})] = 9.29°$
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. $\tan^{-1}[(127 + 168- (1/2)(64))/776] = 23°$ $(90° - 23° = 67°)$

[9] 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.

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-5.

Table V-5
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 1997-2002 NASS CDS, front-outboard, MAIS 1+ occupant injuries, with a lateral delta-V range of 12-25 mph in side crashes, 43% of the injuries are in 3 & 9 o'clock and 90% of the injuries are in 2-3 & 9-10 o'clock directions.

<u>9. NASS and FARS Data for Occupant Injuries in Side Crashes.</u> The analysis assumes that HPS benefits only occupants in the nearside 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 nearside occupant injuries resulted from front occupant compartment crashes, because front occupants are more vulnerable to serious injuries when the front compartment of the vehicle is hit, as opposed to impacts to the rear occupant compartment.

10. Vehicle Impact Speed and Occupant Injuries. The injuries are categorized by lateral vehicle delta-V. The reason for the use of the lateral impact speed[10] 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 a 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

[10] 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.

mph, for the AIS 3 injury. Nevertheless, the use of the lateral impact speed would capture all injuries that would benefit from the proposed tests and exclude those that would not.

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 the head impacts with a pole would be higher than HIC resulting from the head impacts with 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 1997-2001 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 the 201 Upper Interior Head Protection requirements[11]. To reflect the effect of crash mode/environment, the target population is further divided into three (3) subgroups, as shown below:

Case 1. Side Crashes Involving **Vehicle-to-pole crashes:** Table V-6 shows 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

[11] See Appendices D, E and F for the derivation. According to the derivation, a total of 160 lives would be saved by the 201 head protection requirement. (Among the 160 lives, 119 are from vehicle-to-vehicle and 41 are from vehicle-to-pole side crashes.)

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 1997-2001 NASS CDS data, 65% of the injuries are from occupants represented by the 50th percentile test dummy and the remaining 35% of the injuries are from occupants represented by the 5th percentile male test dummy. These percentages were used to separate the injuries.

Table V-6
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 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatality	Total
Head & Face	888	284	10	22	61	177	1,442
Thorax	0	0	44	37	0	113	194
Abdomen	15	0	0	69	0	0	84
Pelvis	0	0	5	0	0	9	14

The remaining population represented by a 5th percentile test dummy

Body Region	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatality	Total
Head & Face	478	153	5	12	33	96	777
Thorax	0	0	23	20	0	61	104
Abdomen	8	0	0	37	0	0	45
Pelvis	0	0	3	0	0	5	8

For the fatalities, 273 resulted from head & face injuries, 174 resulted from chest injuries, none resulted from abdominal injuries and 14 resulted from pelvic injuries. As for the MAIS 3-5 injuries, 143 resulted from head & face injuries, 124 resulted from chest injuries, 106 resulted from abdominal injuries and 8 resulted from pelvic injuries.

Case 2. Side Crashes Involving **Vehicle-to-Other Vehicles or -Roadside Objects**: 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-7. 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 anchorage), the front door components and the roof side rail components[12]. 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-7 below.

Table V-7
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 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatality	Total
Head & Face	6,625	1,675	85	192	197	317	9,091
Thorax	4,905	330	1,501	1,164	21	464	8,385
Abdomen	280	98	26	131	38	152	725
Pelvis	0	0	151	0	0	0	151

The remaining population represented by a 5th percentile test dummy

Body Region	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatality	Total
Head & Face	3,568	902	46	104	106	170	4,896
Thorax	2,641	178	808	626	11	250	4,514
Abdomen	151	52	14	71	21	82	391
Pelvis	0	0	82	0	0	0	82

[12] 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.

For these fatalities, 487 resulted from head injuries, 714 resulted from chest injuries, 234 resulted from abdominal injuries and none resulted from pelvic injuries. As for the MAIS 3-5 injuries, 836 resulted from head injuries, 4,131 resulted from chest injuries, 301 resulted from abdominal injuries and 233 resulted from pelvic injuries.

Case 3. Non-Rollover Side Crashes Involving **Complete Occupant Ejection**: HPS would be effective in reducing side window ejection even if the air bag deflates (i.e., bottoms out). For the analysis, fatalities and injuries resulting from complete occupant ejection cases were considered. Note that since combo HPS with its narrow air bag size may not properly retain occupants, for the benefit derivation, the target population was adjusted by HPS type[13]. (See Benefit section for the derivation.) Fatalities and injuries involving complete occupant ejections in non-rollover side crashes are shown in Table V-8. The target population is divided into two groups by height, and the injuries are categorized by MAIS and body region.

Table V-8
Target Population for Complete Occupant Ejection in
Non-Rollover Side Crashes (for a delta-V of 12 –25 mph)
For Occupant Height of at least 65 inches

Body Region	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatality	Total
Head & Face	0	127	19	8	7	260	421
Thorax	0	0	8	0	0	150	158
Abdomen	0	0	0	0	12	4	16
Pelvis	0	0	0	0	0	0	0

The remaining population represented by a 5th percentile test dummy

Body Region	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	Fatality	Total
Head & Face	0	68	10	4	4	140	226
Thorax	0	0	4	0	0	80	84
Abdomen	0	0	0	0	6	2	8
Pelvis	0	0	0	0	0	0	0

[13] In addition, for the benefit analysis, the target population was adjusted with the 2003 safety belt use rate.

For these fatalities, 400 resulted from head & face injuries, 230 resulted from chest injuries, 6 resulted from abdominal injuries and none resulted from pelvic injuries. As for the MAIS 3-5 injuries, 52 resulted from head & face injuries, 12 resulted from chest injuries, 18 resulted from abdomen injuries and none resulted from pelvic injuries.

Summary of Target Population:

In the 2001 Fatality Analysis Reporting System (FARS) there were 9,088 side impact fatalities. For our target population, we excluded from these side impact fatalities those cases which included rollovers as first event (203), rear seat occupants (732), middle front seat or unknown seat occupants (327), far-side occupants (2,601), children under 12 in the front seat nearside (71), and delta-Vs not in our assumed effectiveness range of 12 to 25 mph (2,084). We also made an adjustment based on the estimated benefits that would result from the FMVSS 201 upper interior requirements for the A-pillar, B-pillar, and roof side rail. This left us with a target population of 2,910 fatalities and 7,248 non-fatal serious to critical AIS 3-5 injuries.

The 2,910 fatalities were divided into three groups for the analysis: (1) vehicle to pole impacts (559), (2) vehicle to vehicle or other roadside objects impacts, which include partial ejections in these cases (1,715), and (3) complete occupant ejections in non-rollovers (636). In this target population, 40 percent of the total fatalities are caused by head/face injuries, 38 percent by chest injuries and 8 percent by abdominal injuries. In contrast, for the 7,248 non-fatal AIS 3-5 target population, chest injuries are the predominate maximum injury source accounting for 59 percent, head/face injuries account for 13 percent, and abdominal injuries account for 6 percent.

Combining all serious to fatal injuries, chest injuries account for 53 percent, head/face injuries account for 20 percent, and abdominal injuries account for 7 percent.

When the head, chest, abdominal and pelvic injuries were further adjusted with the 2003 safety belt usage rate, the increase in usage rate resulted in 2,495 fatalities and 5,853 non-fatal serious to critical AIS 3-5 head, chest, abdominal and pelvic injuries.

A. Overview of Method

The basic benefit estimation procedure consists of four steps: (1) establish the fatality and MAIS 3-5 injury probability (p) for each individual injury criterion (i.e., HIC, rib deflection, abdomen force, pelvic acceleration, pelvic force); (2) calculate the adjusted and weighted performance of HPS; (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 MAIS 3-5 injury probability (p). This step derived fatal/injury probability (p) for each vehicle test data included in the analysis by injury 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 a HIC score of 360 at vehicle delta V of 18 mph when measured with the SID-H3 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:

$r = 1\text{-}(P_a / P_b)$

P_a : average fatality or injury probability of crash test results after setting those with failed values to the proposed criteria. (Note that, alternative to this definition of P_a, where stated, the analysis estimates benefits based on fatality or injury probability setting those to the actual HPS performance results. See following section for further discussion.)

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

Benefits are realized from the proposed injury criteria. The analysis examines the proposed pole tests (both perpendicular and oblique tests) with 50th percentile and 5th percentile test dummies from the previously performed NHTSA sled test, 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.

Step 4. 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 10,152 and none with a HIC score of 360. If head air bags reduce the HIC level from 10,152 to 360 at a vehicle lateral delta-V of 20 mph. Thus, all the fatalities would be saved and, consequently, the air bag effectiveness at this delta-V would be 100%. For the benefit derivation, these 100 lives saved are used. Although the air bag reduced the HIC level by 28 times, some of these occupants would be injured at a vehicle delta-V of 18 mph with the deployed air bag. According to the injury probability curves, there are approximately 34% of MAIS-1, 14% of MAIS-2, 5% of MAIS-3, 1% of MAIS-4, 0% of MAIS-5 and 45.9% of no-injury probabilities. The lives saved are re-distributed according to the injury probabilities at a HIC score of 360[14].

Pole Test Results: The agency has conducted a series of pole tests, and the results are summarized in Tables V-9 thru -12. As discussed previously, unless otherwise stated, any measured injury scores higher than the injury criteria (for example, HIC of 1000 for head, etc.)

[14] There would be 34 AIS-1, 14 AIS 2, 5 AIS 3, 1 AIS-4 and 46 no-injuries.

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) and are shown in the following tables:

Table V-9
Analysis of the Sled Pole Test Results w/ the SID-H3
(with 201 seating procedure)

Speed (mph)	Impact Angle	HPS type	Head (HIC of 1,000)			Chest (TTI of 85/90)			Pelvis (g of 130g's)		
			Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.
18	Per.	None	11,071	9,233	10,152	67.0	58.0	62.5	53.7	49.4	51.6
20	Obl.	None	N/A	N/A	7,493	N/A	N/A	107.0	N/A	N/A	55.6
18	Per.	AC+Th	457	237	333	78.9	36.0	49.1	60.2	40.5	48.7
	Per.	AC	579	183	432	83.0	53.1	66.4	51.5	47.7	49.1
	Per.	ITS+Th	N/A	N/A	340	N/A	N/A	47.0	N/A	N/A	49.0
20	Obl.	AC	N/A	N/A	330	N/A	N/A	Failed	N/A	N/A	81.3
	Obl.	AC+Th	N/A	N/A	Failed	N/A	N/A	57.0	N/A	N/A	57.6
	Obl.	Comb	N/A	N/A	Failed	N/A	N/A	Failed	N/A	N/A	79.2

With the SID-H3 test dummy, the agency tested 4 vehicles at 20 mph oblique. Three of these vehicles were equipped with head/side air bags: two of the vehicles were equipped with a curtain air bag and the other was equipped with a combo air bag. However, none of the vehicles passed all the requirements.

Table V-10
Analysis of HIC Scores w/ the ES-2re
(with the 201 seating procedure)

Speed (mph)	Impact Angle	HPS Type	Head (Min. HIC of 1,000)		
			Max.	Min.	Avg.
18	Per.	None	9,004	4,728	6,866
20	Obl.	None	15,592	11,983	14,242
18	Per.	AC+Th	N/A	N/A	244
	Per.	AC	435	208	321
	Per.	Combo	313	114	180
20	Obl.	AC+Th	N/A	N/A	465
	Obl.	Combo	*	N/A	243
	Obl.	AC	670	629	650

* Failed

Table V-11
Analysis of the Sled Pole Test Results w/ the ES-2re
(with the 214 seating procedure, Oblique Impact at 20 mph)

HPS Type	Head (Min. HIC of 1,000)	Chest (Min. Rib-Def. Of 42 mm)	Lower Spine Acceleration (g)	Abdomen (Min. Force of 2.5 kN)	Pelvis (min. pubic force of 6.0kn)
AC+Th	329	51.2*	51.2	1,547	1,127
Combo	171	49.0*	49.0	1,366	1,733
AC+Th	446	30.7	49.9	1,437	2,463
AC+Th	405	43.4*	50.6	1,165	1,849
Avg.	338	37.1[15]	50.2	1,379	1,793

* Failed to meet the proposed injury criterion.

The air bags test results show an average HIC score of 230 at a vehicle delta-V of 18 mph. At a vehicle delta-V of 20 mph, an average HIC score of 502 was measured with the dummy positioned per the 201 seating procedure and 338 from the 214 seating procedure. Regarding the chest deflection scores in Table V-11, two out of four air bags failed to meet the proposed criteria of 42 mm. Although the air bags failed to meet the proposed deflection requirements, based on the chest deflection results measured with 201 seating procedure, we believe that the air bags would not increase the deflection scores compared to unequipped[16].

Table V-12
Analysis of the Sled Pole Test Results w/ the SID-IIs

Speed (mph)	Impact Angle	HPS	Head (HIC of 1,000)			Lower Spine-g's (82g)		
			Max.	Min.	Avg.	Max	Min	Avg
20	75	None	14362	8,705	11,533	97.3	78.3	87.8
20	75	with	*	*	512	70.1	66.9	68.5

* Failed

With the SID-IIs test dummy, the agency tested 5 vehicles at 20 mph oblique. All of the vehicles were equipped with air bags but only three airbags deployed. Among the three vehicles, only one vehicle passed all the requirements.

[15] The average score is based on air bags that would meet the proposed requirement.
[16] The chest deflection scores measured with the 201 optional pole seating procedure show that air bags reduced chest deflection in both the perpendicular and oblique pole. Therefore, for the benefit analysis, the average score of these failed air bags was used as a proxy for the baseline. See Chapter IV for the test results.

Air bag deployment speed, 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.

All estimates were based on the assumption that there are no changes in occupants demographics, driver/passenger behavior, child restraint use, or the percent of small stature occupant and children sitting in the front seat. In addition, the analysis uses data (1997-2001 NASS CDS, annual, adjusted Front Outboard Occupant Injuries in Non-rollover Side Impacts) to derive the target populations that would be impacted by a head protection system (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 proposed injury values. 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 1,032 lives if vehicles were equipped with curtain and thorax air bags with 4 side impact sensors.

(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 proposed oblique pole test requirements would prevent 307 AIS-5, 443 AIS-4 and 287 AIS-3 injuries in vehicle-to-pole, vehicle-to-vehicle/others side crashes and complete occupant ejection 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[17], the benefits were derived based on the effectiveness of HPS at a vehicle delta-V of 20 mph. The following target population categories were considered for the derivation:

Benefit Derivation for the Vehicle-to-pole Side Crashes (With the ES-2 and SID-IIs Test Dummies):

In the target population section, it was determined that approximately 90% of the target population (within a lateral vehicle delta-V range of 12-25 mph) would be potentially affected by

[17] A vehicle delta-V range of 12 –25 mph was used for the target population, rather than each delta-V.

the proposed oblique pole tests for the 50th and 5th test dummies[18]. For the occupants represented by the ES-2 50th percentile test dummy, the population was adjusted with the factor, as shown in Table V-13:

Table V-13
Vehicle-to-Pole Target Population
(Adjusted with minimum air bag size, impact angle & 50th test dummy)

Body Region	Injury Level					
	MAIS-1	MAIS-2	MAIS-3	MAIS-4	MAIS-5	Fatality
Head and Face	799	256	9	20	55	159
Thorax	0	0	39	33	0	102
Abdomen	13	0	0	62	0	0
Pelvis	0	0	5	0	0	8

Head: 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. For example, even a relatively low impact speed of 15 mph, a head impact would result in a HIC score of 4,490. According to the head injury probability curves, the HIC score would result in 100% probability of death. However, the results in Table V-6 show that there were low severity injuries (such as MAIS-1 and -2) in vehicle-to-pole side crashes. Consequently, the results show that not all vehicle-to-pole crashes result in head-to-pole impacts; the head may impact with a pole/tree, vehicle interior components, or nothing (no-head contact or closed window). To separate head injuries resulting from head-to-pole impacts from the other cases in vehicle-to-pole side crashes, the actual head injury distributions were examined with the injury probability curves.

According to the derived HIC profile, a HIC score of 920 would result from a vehicle delta-V of 20 mph when the head of the ES-2 impacts with the vehicle interior components[19]. At this HIC

[18] See Table 5 in Chapter V. The ranges in angle were converted to o'clock position for the target population.
[19] See Appendix B for the derived HIC profile with respect to vehicle delta-V.

level, there are approximately 14% AIS-1, 40% AIS-2, 32% AIS-3, 11% MAIS-4, 28% MAIS-5 and 0% fatal injury probabilities[20]. As for the no-head contact case, most of the injuries would be AIS-1and -2 injuries, as shown in the BMW sled tests. According to the BMW sled test results, no-head contact would result in a HIC range of 80-190 at a vehicle delta-V of 17 mph, and as discussed in the previous cases, the HIC level would not substantially increase with delta-V. At a HIC score of 190, there are approximately 14% AIS-1, 4% AIS-2, 2% AIS-3, 0% AIS-4, 0% AIS-5 injuries and 0% fatality injury probability. The results are summarized in Table V-14

Table V-14
Head Injury Probability and Injury Source

	HIC	AIS 1	AIS 2	ASI 3	AIS 4	AIS 5	Fatal
Head-to-pole/tree	14242	0.00	0.00	0.00	0.00	0.00	1.00
Head-to-interior components	920	0.14	0.40	0.32	0.11	0.02	0.00
Head-to-open/closed window	190	0.14	0.02	0.00	0.00	0.00	0.00

For each injury level, the injury probability was weighted, as shown below:

Table V-15
Weighted Head Injury Probability and Injury Source

	AIS 1	AIS 2	ASI 3	AIS 4	AIS 5	Fatal
Head-to-pole/tree	0.00	0.00	0.00	0.00	0.00	1.00
Head-to-interior components	0.50	0.90	0.95	0.96	0.98	0.00
Head-to-open/closed window	0.50	0.10	0.05	0.04	0.02	0.00
Total	1.00	1.00	1.00	1.00	1.00	1.00

According to the weighted head injury probability, the target head injuries were distributed, as shown below:

[20] In other words, an occupant has a 85% risk of AIS 2-4 injuries when the head impacts with vehicle interior components at a vehicle delta-V of 20 mph.

Table V-16
Distribution of Head Injuries By Weighted Head Injury
Probability and Injury Source

	AIS 1	AIS 2	ASI 3	AIS 4	AIS 5	Fatal
Head-to-pole/tree	0	0	0	0	0	159
Head-to-interior components	397	230	8	19	54	0
Head-to-open/closed window	402	26	0	1	1	0
Total	799	256	9	20	55	159

With deployed head air bags, the HIC scores would be substantially reduced for the head-to-pole and head-to-vehicle interior components, as shown below:

Table V-17
Head Injury Probability and Injury Source, with Deployed Air Bag

	HIC	AIS 1	AIS 2	ASI 3	AIS 4	AIS 5	Fatal
Head-to-pole/tree	502	0.40	0.26	0.10	0.03	0.00	0.00
Head-to-interior components	374	0.36	0.15	0.06	0.01	0.00	0.00
Head-to-open/closed window	240	0.20	0.07	0.03	0.01	0.00	0.00

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, as shown below:

Table V-18
Effectiveness for Each Injury Level for Head-to-Pole/
Tree In vehicle-to-pole side

	AIS 1	AIS 2	ASI 3	AIS 4	AIS 5	Fatal
Head-to-pole/tree	0.000	0.000	0.000	0.000	0.000	0.999
Head-to-interior components	0.000	0.61	0.82	0.87	0.93	0.97
Head-to-open/closed window	0.000	0.000	0.000	0.000	0.000	0.000

Table V-19
Fatal and Nonfatal Injuries Prevented by Head Air Bag In Head
Impact with Pole/Tree in Vehicle-to-Pole Side Crashes

	AIS 1	AIS 2	ASI 3	AIS 4	AIS 5	Fatal
Population	0	0	0	0	0	159
Effectiveness	0.000	0.000	0.000	0.000	0.000	0.999
Benefits	0	0	0	0	0	159

The results in Table V-19 show that 159 lives would be saved with deployed air bags when head impacts with a pole or tree in vehicle-to-pole 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. According to the vehicle-to-pole test results, a HIC score of 502 would be measured[21] 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 502) according to the injury probability curves[22], as shown in Table V-20.

Table V-20
Redistribution of Fatalities in Vehicle-to-Pole Crashes

	No Injury	**AIS-1**	**AIS-2**	**AIS-3**	**AIS-4**	**AIS-5**	**Total**
Injury Risk Probability	21%	40%	26%	10%	3%	0%	100%
Negative Injury Gain	34	64	41	16	4	0	159

The results in Tables 19 and 20 show that head air bags would save 159 lives but increase 64 AIS 1, 41 AIS 2, 16 AIS 3 and 4 AIS 4 head injuries, annually, as shown below:

Table V-21
Overall Benefits for Head-to-Pole/tree in Vehicle-to-Pole Side Crashes

	AIS-1	**AIS-2**	**AIS-3**	**AIS-4**	**AIS-5**	**Fatality**
Benefits	-64	-41	-16	-4	0	159

With respect to the head-to-interior components case, when the head of a 50th percentile male dummy impacts with the vehicle interior components, according to the case study, a HIC score

[21] Since the HIC baseline for the 214 seating procedure was not available, for the HIC profile, the baseline and deployed 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.

[22] For each AIS level, the benefits were redistributed at lower AIS levels including no-injury according to the weighted risk probability.

of 920 would be measured at a vehicle delta-V of 20 mph. Whereas, with deployed air bags, a HIC score of 374 would be measured. According to the injury risk probability and the number of injuries, benefits were derived for each injury level, as shown below:

Table V-22
Benefits for Head-to-Vehicle Interior Components in
Vehicle-to-Pole Side Crashes

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality	Total
Population	397	230	8	19	54	0	708
Effectiveness	0.00	0.60	0.82	0.87	0.93	0.96	N/A
Benefits	0	140	7	17	50	0	214

The 214 prevented injuries were redistributed with the weighted risk probability at a HIC score of 374, that would be measured with deployed air bags at a vehicle delta-V of 20 mph, as shown below:

Table V-23
Redistribution of Injuries in Vehicle-to-Pole Crashes

	No Injury	AIS-1	AIS-2	AIS-3	AIS-4	AIS-5	Total
Injury Risk Probability	42%	36%	15%	6%	1%	0%	100%
Negative Injury Gain	105	92	12	4	1	0	214

The overall benefits for head-to-vehicle interior components in vehicle-to-pole side crashes are shown in Table V-24.

Table V-24
Overall Benefits for Head-to-Pole/tree in Vehicle-to-Pole Side Crashes

	AIS-1	**AIS-2**	**AIS-3**	**AIS-4**	**AIS-5**	**Fatality**
Benefits	-92	129	3	16	50	0

When there is no head contact or contacts with a side widow, a HIC of 190 or less would be measured at a vehicle delta-V of 27 km/hr (17 mph)[23, 24]. Since deployed air bags would produce a higher HIC scores at this vehicle delta-V, head air bags would be ineffective[25]. Consequently, the potential benefits were not derived.

Table V-25
Overall Head Benefits for Occupants Represented by a 50th
Dummy in Vehicle-to-Pole/tree Side Crashes

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Benefits	-156	88	-13	12	50	159

The results in Table V-25 show that head air bag would save 159 lives, and prevent 50 AIS-5, 12 AIS-4 and 88 AIS 2 head injuries, but the redistribution of these injuries would result in an increase of 13 AIS-3 and 156 AIS 1 injuries.

For the occupants represented by the SID-IIs 5th percentile test dummy, the population was adjusted with the minimum air bag coverage angle (i.e., 90% of the injuries), as shown below:

Table V-26.
Vehicle-to-Pole Target Population
(Adjusted with minimum air bag size, impact angle & **5th**)

Body Region	Injury Level					
	MAIS-1	MAIS-2	MAIS-3	MAIS-4	MAIS-5	Fatality
Head and Face	430	138	5	11	30	86
Thorax	0	0	21	18	0	55
Abdomen	7	0	0	33	0	0
Pelvis	0	0	3	0	0	4

[23] 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.
[24] 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.
[25] See Appendix B, the head impacts with open and closed window.

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

Table V-27
Effectiveness for Each Injury Level for Head-to-Pole/
Tree In vehicle-to-pole side

	AIS 1	AIS 2	ASI 3	AIS 4	AIS 5	Fatal
Head-to-pole/tree	0.000	0.000	0.000	0.000	0.000	0.999
Head-to-interior components	0.000	0.61	0.82	0.87	0.93	0.97
Head-to-open/closed window	0.000	0.000	0.000	0.000	0.000	0.000

Table V-28
Fatal and Nonfatal Injuries Prevented by Head Air Bag In
Head Impact with Pole/Tree in Vehicle-to-Pole Side Crashes

	AIS 1	AIS 2	ASI 3	AIS 4	AIS 5	Fatal
Population	0	0	0	0	0	86
Effectiveness	0.000	0.000	0.000	0.000	0.000	0.999
Benefits	0	0	0	0	0	86

The results in Table V-28 show that 86 lives[26] would be saved with deployed air bags when head impacts with a pole or tree in vehicle-to-pole 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-29.

Table V-29
Redistribution of Fatalities of 5th Percentile Occupants
in Vehicle-to-Pole Crashes

	No Injury	AIS-1	AIS-2	AIS-3	AIS-4	AIS-5	Total
Injury Risk Probability	20%	40%	27%	10%	3%	0%	100%
Negative Injury Gain	18	34	23	9	2	0	86

[26] For population represented by a 5th percentile female test dummy.

The results in Tables 28 and 29 show that head air bags would save 86 lives but increase 34 AIS 1, 23 AIS 2, 9 AIS 3 and 2 AIS 4 head injuries, annually, as shown below:

Table V-30
Overall Benefits for Head-to-Pole/tree in
Vehicle-to-Pole Side Crashes (5th)

	AIS-1	AIS-2	AIS-3	AIS-4	AIS-5	Fatality
Benefits	-34	-23	-9	-2	0	86

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

Table V-31
Nonfatal Injuries Prevented by Head Air Bag In Head Impact
with Vehicle Interior Components in Vehicle-to-Pole Side Crashes

	AIS 1	AIS 2	ASI 3	AIS 4	AIS 5	Fatal	Total
Population	214	124	4	10	29	0	381
Effectiveness	0.000	0.61	0.82	0.87	0.93	0.967	N/A
Benefits	0	75	4	9	27	0	115

The 115 injuries prevented were redistributed with the weighted risk probability at a HIC level of 374, as shown below:

Table V-32
Redistribution of Injuries Prevented in
Vehicle-to-Pole Side Crashes

	No Injury	AIS-1	AIS-2	AIS-3	AIS-4	AIS-5	Total
Injury Risk Probability	42%	36%	15%	6%	1%	0%	100%
Negative Injury Gain	86	25	3	1	0	0	115

The results in Tables 31 and 32 were combined to derive the overall benefits for the head impacts with the vehicle interior components, as shown below:

Table V-33
Overall Benefits for Head-to-Vehicle Interior Components in Vehicle-to-Pole Side Crashes

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Benefits	-25	73	3	9	27	0

From the results in Tables 30 and 33, the overall benefits for occupants represented by a 5th female test dummy were derived, as shown below:

Table V-34
Head Benefits for Occupants Represented by a 5th Percentile Female Test Dummy in Vehicle-to-Pole Sides Crashes

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Benefits	-60	50	-6	6	27	86

The results in Table 34 show that head air bags would saved 86 lives, 27 AIS 5, 6 AIS 4, and 50 AIS 2 head injuries, annually. However, bags would increase 6 AIS 3 and 60 AIS 1 injuries.

For all occupants in vehicle-to-pole/tree side crashes, the results in Tables 25 and 34 were combined, as shown below:

Table V-35
Overall Head Benefits in Vehicle-to-Pole/tree Side Crashes

Occupants	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatal
50th	-156	88	-13	12	50	159
5th	-60	50	-6	6	27	86
Total	-216	138	-19	18	76	245

The results in Table 35 show that head air bags would saved 245 lives, 76 AIS 5, 18 AIS 4 and 138 AIS 2 injuries, annually. However, bags would increase 19 AIS 3 and 216 AIS 1 injuries.

Chest: There are two major concerns for the chest benefit derivation[27]: First, we only have the AIS-3+ and AIS-4+ injury risk curves. Consequently, we do not know AIS-5 or fatality risk result from chest injuries in vehicle-to-pole side crashes. Second, it appears that the pole test may not represent real world crashes that result in serious chest injuries or fatalities. Thus, the effectiveness derived from the pole test may not be appropriate for the serious chest injuries and fatalities. Regarding the first concern, the pole test results indicate that the chest of an occupant would experience a (chest) deflection of approximately 47 mm[28] at a lateral vehicle delta-V of 19.3 mph (oblique delta-V of 20 mph)[29]. According to the chest injury risk curves, there are 55% probability of AIS-3+ and 25% of AIS-4+ injury probabilities at a chest deflection of 47 mm, as shown in Figure V-3.

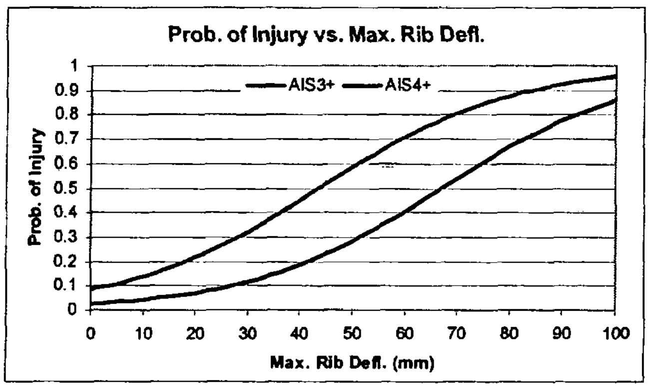


Figure V-3. Probability of AIS 3+ and AIS 4+ Injury as a Function of Maximum ES-2 Rib Deflection

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 47 mm. In other words, the chest fatal injury risk is much lower than 25 percent (of the AIS 4+) at a vehicle oblique delta-V of 20 mph.

[27] For the 50th, the benefit derivation is based on chest deflection.

[28] The average chest deflection is derived from the 99 Volvo S80 (48.6 mm), 2000 Saab (49.4 mm) and 2004 Camry (43.4 mm) pole tests where the air bags failed to meet the proposed 42 mm chest deflection. These tests were performed with the 214 seating procedure with the ES-2re.

[29] Cosine 15° x 20 mph = 19.3 mph.

Regarding the second concern, according to the AIS 3+ injury risk curve, there is a 25% probability of AIS 4+ at a chest deflection of 47 mm[30]. However, distribution of the actual chest injuries in the target population shows that approximately 70% of the chest injuries are AIS 4+. This discrepancy indicates that the pole test may not represent the worst crash scenario for chest in side crashes. Since the target population was distributed by MAIS level rather than by AIS level, it is not feasible to determine whether distribution of the actual injuries is similar to the injuries predicted by the injury probability curves. Thus, it is not feasible to separate chest injuries resulting from crash environments simulated by the vehicle-to-pole test from other crash environments such as the chest impacts directly with a pole/tree. (For example, some of the fatalities would result from side crashes where the chest impacts directly with a pole/tree. The chest deflection resulted from these impacts could be considerably higher than the chest deflection measured in the pole test at the same vehicle delta-V.) Therefore, the effectiveness based on the pole test data could result in an overestimation of the benefit, especially for severe chest injuries.

For the benefit derivation, the effectiveness derived from the vehicle-to-pole test results was used for the AIS-3 injuries, as shown below:

Table V-36
AIS 3 Chest Injuries Prevented for Occupants
Represented by the 50th Male Test Dummy

Vehicle Delta-V (mph)	Effectiveness	Target Population	Injuries Prevented
12-25	0.29 (at 20 mph)	39	11 AIS 3

[30] As shown in Figure V-3, the air bag effectiveness for fatality (i.e., percent reduction rate of fatality) would be lower than the air bag effectiveness for AIS 5+.

However, we assumed that the effectiveness for AIS-4, -5 and fatal injuries is ½ of the effectiveness derived for AIS-3 injuries[31]. Based on the assumed effectiveness, the benefits were calculated for AIS-4 and fatal injuries, as shown in Table V-37.

Table V-37
AIS-4+ Injuries Prevented
(for Occupants Represented by 50th Test Dummy)

Vehicle Delta-V (mph)	Effectiveness	Target Population	Injuries Prevented and Lives Saved
12-25	0.14 (at 20 mph)	135	15 lives and 5 AIS-4

The results in Table V-29 show that 15 lives and 5 AIS-4 injuries would be saved and prevented. The injuries prevented and lives saved were redistributed at the chest deflection level predicted by the deployed air bag according to the injury probability. However, since only the AIS-3+ and AIS-4+ injury probability curves are available, all of the injuries prevented and lives saved were assumed to result in AIS-1, -2 and -3 injuries.

With the deployed air bag, a chest deflection of 30.7 mm would be measured at a vehicle oblique delta-V of 20 mph, according to the vehicle-to-pole crash test results. At a chest deflection of 30.7 mm, there is a 33% AIS-3+ injury probability. In other words, 67% of the chest injuries prevented by the air bag would results in AIS-1 or –2 injuries. According to these injury probabilities, the lives saved and injuries prevented[32] were redistributed, as shown in Table V-38.

[31] Regarding AIS-3 injury, there is 29% risk at a chest deflection of 47 mm and 21% risk at a deflection of 30.7 mm. The corresponding air bag effectiveness is 28% (1- 0.21/0.28).
[32] Form Tables 36 and 37, 11 AIS 3 and 5 AIS 4 injuries prevented, and 15 lives saved.

Table V-38
Redistribution of AIS 3+ and Fatal Chest Injuries Prevented by Deployed Air bag in Vehicle-to-Pole Crashes

	AIS 1	AIS-2	AIS-3	Total
Estimated Injury Distribution	33.5%	33.5%	33%	100%
Negative Injury Gain	10	10	10	31

The overall chest benefits for occupants represented by a 50th percentile male test dummy are shown in Table V-39

Table V-39
Overall Chest Injury Distribution for Vehicle-to-Pole Side Crashes for Occupant Represented by 50th Test Dummy

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Without air bag	0	0	39	33	0	102
With deployed air bag	10	10	38	28	0	87
Net saved	-10	-10	1	5	0	15

The results in Table V-39 show that the air bag would save 15 lives and prevent 5 AIS-4 and 1 AIS-3 chest injuries. However, bags would increase 10 AIS 1 and 10 AIS 2 injuries[33], annually.

For the occupant represented by the SID-IIs 5th percentile test dummy, for the 21 AIS 3 injuries, the effectiveness based on the AIS 3+ and 4+ chest injuries was used, as shown in Table V-40.

Table V-40
AIS-3 Chest Injuries Prevented

Vehicle Delta-V (mph)	Effectiveness	Target Population	Injuries Prevented
12-25	0.05 (at 20 mph)	21	1

The results in Table V-35 show that thorax air bags would prevent 1 AIS-3 injury.

As for AIS 4+ nonfatal and fatal injuries, we assumed 1/2 of the AIS 3 effectiveness score (derived from the vehicle-to-pole test results), as shown in Table V-41.

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

Table V-41
AIS-4+ Chest Injuries Prevented

Vehicle Delta-V (mph)	Effectiveness	Target Population	Injuries Prevented and Lives Saved
12-25	0.02 (at 20 mph)	73	1 life

The results in Table V-41 show that one life would be saved. Similar to the methodology used for the target population represented by the 50th test dummy, the chest injuries prevented and lives saved were assumed to result in AIS 1, 2 and 3 injuries. With the deployed air bag, a lower spine acceleration of 69g would be measured with the SID-IIs 5th percentile female test dummy at a vehicle oblique delta-V of 20 mph. At a lower spine acceleration of 69g, there is a 52% AIS-3+ injury probability. Accordingly, the chest injuries prevented were redistributed with the probability, as shown in Table V-42.

Table V-42
Redistribution of AIS 3 and 4+ Chest Injuries

	AIS 1	AIS 2	AIS-3	Total
Estimated Injury Distribution	24%	24%	52%	100%
Negative Injury Gain	1	1	1	3

Table V-43
Overall Chest Injury Benefits for 5th in Vehicle-to-Pole Side Crashes

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Without Air bag	0	0	21	18	0	55
With deployed Air bag	1	1	22	18	0	54
Net Saved	-1	-1	-1	0	0	1

The results in Table V-43 show that thorax air bags would save 1 life. However, bags would increase one injury for each AIS 1, 2 and 3 injury level.

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-2) and 5th (SID-IIs) dummies are used in the oblique pole test, as shown in Table V-44.

Table V-44
Lives Saved and Injuries Prevented for All Chest Injuries
Affected by Head and Thorax Air Bags in Vehicle-to-Pole Side Crashes

Occupants	AIS 1	AIS 2	AIS 3	AIS 4	AIS-5	Fatality
50th	-10	-10	1	5	0	15
5th	-1	-1	-1	0	0	1
Total	-11	-11	0	5	0	16

The results in Table V-44 show that HPS would save 16 lives and 5 AIS-4 injuries. However, bags would increase 11 AIS 2 and 11 AIS 1 chest injuries in vehicle-to-pole side crashes.

Abdomen: The pole test results indicate that the abdomen of an occupant would experience a force 1,928N at a vehicle delta-V of 20 mph[34]. According to the abdomen injury risk curves, there is a less than 1% chance of an AIS-4+ injury at an abdomen force of 1,928N[35]. With a deployed airbag, an abdomen force of 1,339N was measured at a vehicle delta-V of 20 mph. According to the probability of AIS 3+ and AIS 4+ abdominal injury based on Walfisch and Viano, the reduction in abdomen force would be insignificant in reducing AIS 4+ injuries and fatalities, as shown in Figure V-4.

[34] Since all the air bags tested with the 214 seating procedure met the injury criterion and that there is no baseline available for abdomen, the abdominal force results from the 201 seating procedure were used as a proxy.
[35] However, the distribution of the (actual) injuries shows that serious injuries (AIS-4+) occurred at this vehicle impact speed.

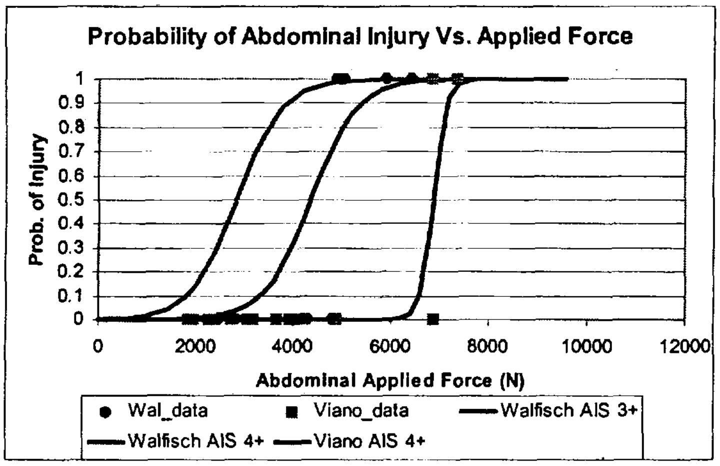


Figure V-4. Probability of AIS 3+ and AIS 4+ Abdominal Injury based on Walfisch and Viano

The Walfisch and Viano AIS 4+ injury probability curves in Figure V-6 clearly show that the reduction in abdomen force would not produce any significant reduction in AIS 4+ injuries in the data range. Thus, the abdomen benefit estimation was not performed for the AIS 4+ injuries.

As for the remaining 14 AIS-1 injuries, since the corresponding effectiveness is not available, the benefits were not estimated.

For the occupant represented by the SID-IIs 5th percentile test dummy, since the injury criterion is not proposed in the NPRM, benefits were not estimated.

Pelvis: The pole test results indicate that the pelvis of an occupant would experience a force 2,609N at a vehicle delta-V of 20 mph[36]. According to the pelvic injury risk curves, there is a less than 1% probability of AIS-4+ injuries at a pelvic force of 2,609N. With the deployed side air bag, the force reduced to 2,287N. According to the probability of pelvic injury and ES-2

[36] Due to limited test data on public force, the pubic forces measured with the 201 seating procedure were used as a proxy measurement. With deployed air bags, the dummy positioned according to the 214 seating procedure produced a pubic force range of 1,165 to 1,547 N in the proposed oblique pole test.

pubic symphysis force, as shown in Figure V-5, side air bags would be ineffective in reducing fatalities at a vehicle delta-V of 20 mph. Thus, it was determined that no lives would be saved with the HPS in vehicle-to-pole side crashes.

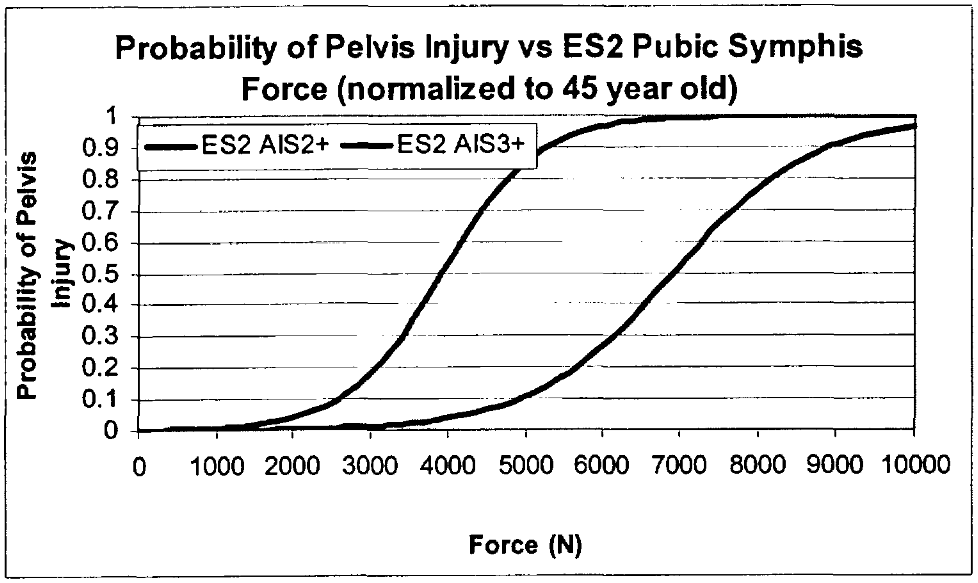


Figure V-5. Probability of AIS 2+ and AIS 3+ pelvic injury as a function of ES-2 public symphysis force

As for the remaining 5 AIS-3 injuries, the effectiveness derived from the vehicle-to-pole test results was used to calculate AIS-3 injuries prevented[37], as shown in Table V-45.

Table V-45
AIS-3 Injuries Prevented

Vehicle Delta-V (mph)	Effectiveness	Target Population	Injury Prevented
12-25	0.39 (at 20 mph)	5	2

The results in Table V-45 show that 2 AIS-3 injuries would be prevented.

The revised injury distribution is shown in Table V-46.

[37] There is a 5.82% and 9.56% probability without and with air bags, respectively. The effectiveness is derived as: Effectiveness = 1-5.82/9.56.

Table V-46
Revised Pelvis Injury Distribution for Vehicle-to-Pole
Side Crashes for Occupant Represented by 50th Test Dummy

	AIS-3	Fatality
Without Air bag	5	8
With deployed Air bag	3	8
Net Saved	2	0

The results in Table V-46 show that the air bag would prevent 2 AIS-3 pelvic injuries.

For the occupant represented by the SID-IIs 5th percentile test dummy, as discussed in Chapter V, due to limited data, the benefits for pelvis were not estimated.

For vehicle-to-pole side crashes, the analysis indicates that the HPS would save 261 fatalities, 76 AIS-5, 23 AIS-4 and 127 AIS 2 injuries annually when the proposed oblique pole test with the ES-2 and SID-IIs is adopted. However, the redistribution of the lives saved and injuries prevented would cause a gain of 17 AIS-3 and 227 AIS 1 injuries, as shown below:

Table V-47
Overall Benefits for All Occupants in Vehicle-to-Pole Side Crashes

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Head	-216	138	-19	18	76	245
Chest	-11	-11	0	5	0	16
Abdomen	0	0	0	0	0	0
Pelvis	0	0	2	0	0	0
Total	-227	127	-17	23	76	261

<u>Benefit Derivation for the 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 proposed oblique pole test for the 50th and 5th test dummies.

For the occupant represented by the ES-2 test dummy, the population was adjusted with the percentage, as shown in Table V-48.

Table V-48
Target Population for Vehicle-to-vehicle or Other Objects
(Adjusted with minimum air bag size, impact angle & **50th** test dummy)

Body Region	Injury Level (Adjusted with FARS)					
	MAIS-1	MAIS-2	MAIS-3	MAIS-4	MAIS-5	Fatality
Head and Face	5,963	1,508	76	173	177	285
Thorax	4,415	297	1,351	1,047	19	418
Abdomen	252	88	23	118	34	137
Pelvis	0	0	136	0	0	0

Head: As discussed, when the head of an occupant impacts with the vehicle interior components at the given delta-V range, the head would experience relatively low HIC levels. At these HIC levels, serious head injuries or fatalities would seldom occur. For example, there are approximately only 1.8% and 0.1% probabilities of AIS 5 and fatality, respectively, when the head impacts with the vehicle interior components at a vehicle delta-V of 20 mph. Therefore, the serious injuries in the target population would result from head impacts with rigid external objects such as the front of the striking vehicle in vehicle-to-vehicle/others objects for the given vehicle lateral delta-V range of 12 - 25 mph. As discussed in the head impacts with the front surface of the striking vehicle (hypothetical) case, the resulting head injuries would be similar to injuries resulting from the head impacts with a pole or tree. To further investigate the similarity, normalized relative risk distributions of the vehicle-to-pole and vehicle-to-vehicle/others were compared, as shown in Table V-49 and Figure V-6.

Table V-49
Relative Risk Distribution of Head/face Injuries and
Fatalities Between Vehicle-to-Pole and Vehicle-to-vehicle/Others (50th)

Side Crashes	MAIS-1	MAIS-2	MAIS-3	MAIS-4	MAIS-5	Fatal	Total
Vehicle-to-Pole	62% (799)	20% (256)	1% (9)	2% (20)	4% (55)	12% (160)	100% (1,299)
Vehicle-to-Vehicle & Others	73% (5,963)	18% (1,508)	1% (76)	2% (173)	2% (177)	4% (285)	100% (8,182)

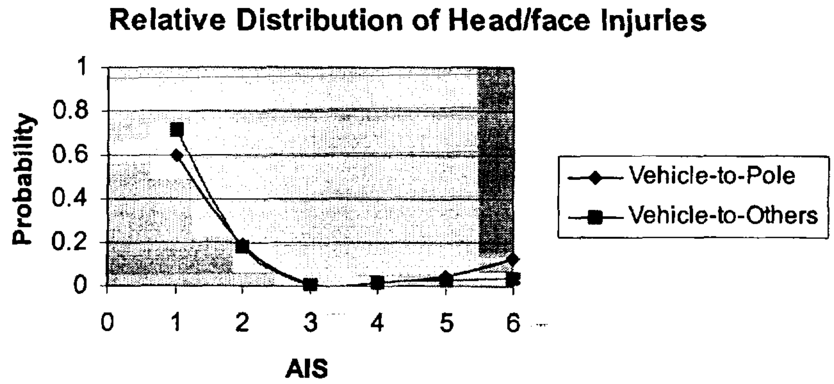


Figure V-6. Normalized Relative Risk Distribution of Head/face

The normalized relative risk distributions in Figure V-6 show that they are very similar in terms of injury distribution and that most injuries are either AIS 1 or 2. In addition, the relative fatality rate of the vehicle-to-vehicle/others crashes is about three times lower than the relative fatality rate of the vehicle-to-pole crashes[38].

Similar to the methodology used for the vehicle-to-pole crashes, the target population was divided into three groups: head impacts with the striking vehicle, head impacts with the vehicle interior components and head impacts with open or closed window. In addition, due to limited data, the effectiveness derived for the head impacts with a pole case was used as a proxy for the

[38] It implies that probability of head impacts with rigid objects, such as the front of the striking vehicle; in vehicle-to-vehicle/others is about three times lower when compared to the probability of head impacts with a pole or tree in vehicle-to-pole side crashes, given that such crashes occurred.

head impacts with the striking vehicle in vehicle-to-vehicle/others side crashes. The target population for each group distributed by the weighted injury probability is shown in Table V-50.

Table V-50
Head Injury Distribution by Injury Source in
Vehicle-to-Vehicle Side Crashes

	AIS 1	**AIS 2**	**AIS 3**	**AIS 4**	**AIS 5**	**Fatality**
Striking Vehicle	0	0	0	0	0	285
Vehicle Interior Components	2963	1356	73	166	174	0
Open or Closed Window	3000	151	4	7	3	0
Total	5963	1508	77	173	177	285

For the head impacts with the striking vehicle case, the previously derived head-to-pole effectiveness was applied to each injury target population[39], as shown in Table V-51.

Table V-51
Head Benefits for Head Impacts with Striking Vehicle
Case in Vehicle-to-Vehicle/Others

	AIS 1	**AIS 2**	**AIS 3**	**AIS 4**	**AIS 5**	**Fatality**
Population	0	0	0	0	0	285
Effectiveness	0.0	0.0	0.0	0.0	0.0	0.999
Benefits	0	0	0	0	0	285

The lives saved were redistributed with the weighted risk probability at a HIC score of 502 that is expected with deployed air bags at a vehicle delta-V of 20 mph, as shown in Table V-52.

Table V-52
Redistribution of Lives Saved For Head-to-Striking
Vehicle in Vehicle-to-Vehicle Side Case

	AIS 1	**AIS 2**	**AIS 3**	**AIS 4**	**AIS 5**	**Fatality**
Probability	40%	26%	10%	3%	0%	0%
Negative Gain	115	74	28	7	1	0

[39] Although HIC scores from head-to-pole impacts would be higher than head-to-striking vehicle impacts, head air bags would be equally effective in reducing HIC scores. See additional discussion in Appendix B.

The results from Tables V-51 and -52 were combined to calculate overall benefits for the head impacts with the striking vehicle in vehicle-to-vehicle side crashes, as shown in Table V-53.

Table V-53
Overall Head Benefits for Head-to-Striking
Vehicle in Vehicle-to-Vehicle Side Crashes

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Benefits	-115	-74	-28	-7	-1	285

The results in Table V-53 show that head air bags would saved 285 lives for head impacts with the striking vehicle case in Vehicle-to-Vehicle side crashes. However, head air bags would increase 1 AIS 5, 7 AIS 4, 28 AIS 3, 74 AIS 2 and 115 AIS 1 head injuries, annually.

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

Table V-54
Head Benefits for Head-to-Vehicle Interior Components
Case in Vehicle-to-Vehicle Side Crashes

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Population	2963	1356	73	166	174	0
Effectiveness	0.0%	61%	82%	87%	93%	97%
Benefits	0	827	60	145	161	0

The injuries prevented were redistributed with the weighted risk probability at a HIC score of 374 that would be measured with deployed air bags at a vehicle delta-V of 20 mph, as shown in Table V-55.

Table V-55
Redistribution of Injuries Prevented in Head Impacts
with Vehicle Components in Vehicle-to-Vehicle Side Crashes

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5
Probability	36%	15%	6%	1%	0
Negative Gain	520	58	18	2	0

The results in Table V-54 and -55 were combined to derive overall head benefits for the head-to-vehicle interior components case in vehicle-to-vehicle side crashes, as shown in Table V-56.

Table V-56
Overall Head Benefits for Head-to-Interior components
in Vehicle-to-Vehicle Side Crashes.

	AIS 1	**AIS 2**	**AIS 3**	**AIS 4**	**AIS 5**	**Fatality**
Benefits	-520	769	42	143	161	0

The results in Tables V-53 and -56 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-57
Head Benefits for Occupants Represented by 50th
Percentile Male Dummy in Vehicle-to-Vehicle Side Crashes

	AIS 1	**AIS 2**	**AIS 3**	**AIS 4**	**AIS 5**	**Fatality**
Benefits	-635	696	13	135	161	285

The results in Table V-57 show that head air bags would save 285 lives and prevent 161 AIS 5, 135 AIS 4 and 13 AIS 3 and 696 AIS 2 head injuries, annually. However, air bags would increase 635 AIS 1 head injuries.

For the occupants represented by the SID-IIs 5th percentile test dummy, the target population was adjusted with the factor (90%), as shown in Table V-58.

Table V-58
Vehicle-to-vehicle or Other Objects Target Population
(Adjusted with minimum air bag size, impact angle & 5th population)

Body Region	Injury Level					
	MAIS-1	MAIS-2	MAIS-3	MAIS-4	MAIS-5	Fatality
Head and Face	3,211	812	41	100	95	153
Thorax	2,377	160	727	563	10	225
Abdomen	136	47	13	64	19	74
Pelvis	0	0	74	0	0	0

Similar to the methodology used for the 50th population, the target population was divided into three groups: head impacts with the striking vehicle, head impacts with vehicle interior components and finally head impacts with open or closed window, as shown in Table V-59.

Table V-59
Head Injury Distribution of 5th Percentile Occupants by
Injury Source in Vehicle-to-Vehicle Side Crashes

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Striking Vehicle	0	0	0	0	0	153
Vehicle Interior Components	1595	730	39	90	94	0
Open or Closed Window	1616	82	2	4	2	0
Total	3211	812	41	93	95	153

For the head impacts with the striking vehicle case, the previously derived effectiveness was applied to each injury target population, as shown in Table V-60.

Table V-60
Head Benefits for 5th Percentile Occupants for Head
Impacts with Striking Vehicle Case in Vehicle-to-Vehicle/Others

	AIS 1	**AIS 2**	**AIS 3**	**AIS 4**	**AIS 5**	**Fatality**
Population	0	0	0	0	0	153
Effectiveness	0.0	0.0	0.0	0.0	0.0	0.999
Benefits	0	0	0	0	0	153

The results in Table V-60 show that head air bags would save 153 lives annually. The lives saved were redistributed with the weighted risk probability a HIC score of 512 that would be measured at a vehicle delta-V of 20 mph with deployed head air bags, as shown in Table V-61.

Table V-61
Redistribution of Lives Saved For 5th Percentile Occupants For
Head-to-Striking Vehicle in Vehicle-to-Vehicle Side Case

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5
Probability	40%	27%	10%	3%	0%
Negative Gain	62	41	16	4	0

The results from Tables 60 and 61 were combined to calculate overall benefits for the head impacts with the striking vehicle in vehicle-to-vehicle side crashes, as shown in Table V-62.

Table V-62
Overall Head Benefits for 5th Percentile Occupants for
Head-to-Striking Vehicle in Vehicle-to-Vehicle Side Crashes

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Benefits	-62	-41	-16	-4	0	153

The results in Table V-62 show that head air bags would save 153 lives, represented by a 5th percentile female test dummy. However, air bags would increase 4 AIS 4, 16 AIS 3, 41 AIS 2 and 62 AIS 1 injuries, annually.

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-63.

Table V-63
Head Benefits for Occupant Represented by a 5th Percentile Dummy for Head-to-Vehicle Interior Components Case in Vehicle-to-Vehicle Side Crashes

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality	Total
Population	1595	730	39	90	94	0	2548
Effectiveness	0.0%	61%	82%	87%	93%	97%	N/A
Benefits	0	445	32	78	87	0	642

The 642 injuries prevented were redistributed at a HIC score of 374 that would be measured with deployed head air bags at a vehicle delta-V of 20 mph, as shown in Table V-64.

Table V-64
Redistribution of Injuries Prevented in Head Impacts with Vehicle Components in Vehicle-to-Vehicle Side Crashes

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Probability	36%	15%	6%	1%	0	0
Negative Gain	280	31	10	1	0	0

The results in Table V-63 and 64 were combined to derive overall head benefits for the head-to-vehicle interior components case in vehicle-to-vehicle side crashes, as shown in Table V-65.

Table V-65
Overall Head Benefits for Head-to-Interior Components in Vehicle-to-Vehicle Side Crashes.

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Benefits	-280	414	23	77	87	0

The results in Tables V-62 and 65 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-66
Head Benefits for Occupants Represented by 5th Percentile Female Dummy in Vehicle-to-Vehicle Side Crashes

	AIS 1	**AIS 2**	**AIS 3**	**AIS 4**	**AIS 5**	**Fatality**
Benefits	-342	373	7	73	86	153

For all occupants in vehicle-to-vehicle/Others side crashes, the results in Tables V- 58 and 66 were combined, as shown in Table V-67.

Table V-67
Overall Head Benefits for all Occupants in
Vehicle-to-Vehicle/Others Side Crashes

Occupants	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
50th	-635	696	13	135	162	285
5th	-342	373	7	73	87	153
Total	-976	1,069	20	208	249	438

The results in Table V-67 show that head air bags would save 438 lives and prevent 249 AIS 5, 208 AIS 20 and 1,069 AIS 2 injuries. However, head air bags would increase 976 AIS 1 injuries, annually.

Chest: For the 1,351 AIS 3 chest injuries, due to limited data, the effectiveness derived for the vehicle-to-pole test results was used as a proxy for these injuries, as shown below:

Table 68
AIS 3 Chest Injuries Prevented for Occupants Represented
by 50th Male Test Dummy in Vehicle-to-Vehicle/Others Side Crashes

Vehicle Delta-V (mph)	Effectiveness	Target Population	Injuries Prevented
12 - 25	29%	1351	388

The results in Table V-68 show that thorax air bags would prevent 388 AIS 3 chest injuries, annually.

Regarding AIS 4+ injuries and fatalities, similar to the methodology used for the vehicle-to-pole crashes, ½ of the effectiveness score derived from the pole test was used as a proxy for the AIS-4+ injuries and fatalities, as shown in Table V-69.

Table V-69
AIS-4+ Chest Injury Prevented and Lives Saved

Vehicle Delta-V (mph)	Effectiveness	Target Population (fatalities and AIS-5 injuries)	Lives Saved and AIS-4+ Injury Prevented
12 – 25	0.14 (at 20 mph)	1,484	60 lives, 3 AIS-5, 151AIS-4

The results in Table V-69 show that 60 lives and 3 AIS-5, 151 AIS-4 chest injuries would be saved and prevented with deployed air bags in vehicle-to-vehicle/others crashes. The injury prevented and lives saved were redistributed at a chest deflection of 30.7 mm (that would be expected with a deployed air bag at a lateral vehicle delta-V of 20 mph[40]). However, since only AIS-3+ and AIS-4+ injury probability curves are available, all of the AIS-4+ injuries prevented were assumed to result in AIS-1, -2 and -3 injuries.

With the deployed air bag, as mentioned, a chest deflection of 30.7 mm would be measured at a vehicle delta-V of 20 mph. At a chest deflection of 30.7 mm, there are 33% AIS-3+ and 67% AIS-1&-2 injury probabilities. The 212 injuries and fatalities prevented by the deployed air bag were redistributed with these percentages[41], as shown in Table V-70.

Table V-70
Redistribution of AIS-4+ Chest Injuries Prevented by
Deployed Air bag in Vehicle-to-Vehicle/others Crashes

	AIS 1	AIS 2	AIS 3	Total
Estimated Injury Distribution	33.5%	33.5%	33.0%	100%
Negative Injury Gain	202	202	198	602

[40] When measured with the 214 seating procedure.
[41] Assumed that all redistributed are AIS-1, -2 or -3 injuries.

The overall chest benefits for occupant represented by a 50th percentile male test dummy in vehicle-to-vehicle/other side crashes are shown in Table V-71.

Table V-71
Overall Chest Injuries Prevented for Occupants Represented by 50th Test Dummy in Vehicle-to-Vehicle/Others Side Crashes

	AIS 1	**AIS 2**	**AIS 3**	**AIS 4**	**AIS 5**	**Fatality**
Without air bag	4414	297	1351	1047	19	418
With Deployed air bag	4616	499	1161	896	16	358
Net Saved	-202	-202	190	151	3	60

The results in Table V-71 show that thorax air bags would saved 60 lives and prevent 3 AIS 5, 151 AIS 4 and 190 AIS 3 chest injuries for occupants represented by a 50th percentile male test dummy. However, thorax air bags would increase 202 AIS 1 and 202 AIS 2 injuries, annually.

For the occupants represented by the SID-IIs 5th percentile test dummy, for the 727 AIS 3 chest injuries, the effectiveness derived based on AIS 3+ and 4+ chest injuries was used as a proxy, as shown in Table V-72.

Table V-72

AIS 3 Chest Injuries Prevented for Occupants Represented by 5th Female Dummy in Vehicle-to-Vehicle/others Side Crashes

Vehicle Delta-V (mph)	Effectiveness	Target Population	Injuries Prevented
12 - 25	5%	727	36

The results in Table V-72 show that thorax air bags would save 36 AIS 3 injuries for occupants represented by a 5th female test dummy in vehicle-to-vehicle/others side crashes, annually.

As for AIS 4+ nonfatal and fatal injuries, we assumed 1/2 of the AIS 3 effectiveness score for the AIS-4+ fatal and nonfatal injuries, as shown in Table V-73.

Table V-73
AIS-4+ Chest Injuries Prevented for Occupant
Represented by 5th Percentile Female Test Dummy

Vehicle Delta-V (mph)	Effectiveness	Target Population	Injuries prevented and Lives Saved
12 - 25	0.02 (at 20 mph)	799	6 lives, 14 AIS-4

The results in Table V-73 show that 6 lives and 14 AIS-4 injuries would be saved and prevented with the HPS for the population represented by the 5th female test dummy[42].

With the deployed air bag, a lower spine acceleration of 69 g would be measured with the SID-IIs 5th percentile female test dummy at a vehicle delta-V of 20 mph. At a lower spine acceleration of 69g, there is a 61.5% AIS-3+ injury probability. Accordingly, the chest injuries prevented were redistributed with these probabilities, as shown in Table V-74.

Table V-74
Redistribution of AIS-3+ Chest Injuries and Fatalities
Prevented by Deployed Air Bag for Occupants
Represented by 5th Female Test Dummy

	AIS 1	**AIS 2**	**AIS 3**	**Total**
Estimated Injury Distribution	19%	19%	62%	100%
Negative Injury Gain	11	11	34	56

The results in Tables 72, 73 and 74 were combined to derive net benefits, as shown in Table V-75.

[42] All of the AIS-4+ injuries and lives saved were assumed to result in AIS-1, -2 and -3 injuries, when they are redistributed.

Table V-75
Overall Chest Benefits for Occupants Represented by
5^{th} Percentile Female Test Dummy in
Vehicle-to-Vehicle/Others Side Crashes

	AIS 1	**AIS 2**	**AIS 3**	**AIS 4**	**AIS 5**	**Fatality**
Benefits	-11	-11	2	14	0	6

The revised injury distribution for occupants represented by 5^{th} test dummy in vehicle-to-vehicle/other side crashes is shown in Table V-76.

Table V-76
Revised Chest Injury Distribution for Vehicle-to-Vehicle/Others Side Crashes

	AIS 1	**AIS 2**	**AIS-3**	**AIS-4**	**AIS-5**	**Fatality**
Without Air bag	2377	160	727	564	10	225
With deployed Air bag	2388	171	725	550	10	219
Net Saved	-11	-11	2	14	0	6

The results in Table V-76 show that thorax air bags would save 6 lives and prevent 14 AIS 4 and 2 AIS3 injuries, annually, for occupants represented by a 5^{th} female test dummy. However, thorax bags would increase 11 AIS 1 and 11 AIS 2 injuries.

The revised injuries distributions were combined to derive the net benefit for chest injuries in vehicle-to-vehicle/others crashes for all occupants when the 50^{th} (ES-2) and 5^{th} (SID-IIs) test dummies are used in the oblique pole test, as shown in Table V-77.

Table V-77
Revised Chest Injury Distribution for
Vehicle-to-Vehicle/Others Side Crashes

Occupants	**AIS 1**	**AIS 2**	**AIS-3**	**AIS-4**	**AIS-5**	**Fatality**
50^{th}	-202	-202	190	151	3	60
5^{th}	-11	-11	2	14	0	6
Total	-212	-212	191	164	3	66

The results in Table V-77 show that thorax air bags would save 66 lives and prevent 3 AIS 5, 164 AIS 4 and 191 AIS 3 chest injuries, annually, in vehicle-to-vehicle/others. However, these bags would increase 212 AIS 1 and 212 AIS 2 injuries.

Abdomen: An abdomen force of 1,928N was measured at a vehicle delta-V of 20 mph in the pole test. At this force level, there is a less than 1% risk of AIS 4+. With a deployed airbag, an abdomen force of 1,339N was measured at a vehicle delta-V of 20 mph. As discussed, according to the probability of AIS 3+ and AIS 4+ abdominal injury based on Walfisch and Viano, the reduction in abdomen force would be insignificant in reducing AIS 4+ injuries and fatalities. Thus, the abdomen benefit estimation was not performed.

As for the remaining 23 AIS 3 injuries, the benefits were calculated with the effectiveness derived from the vehicle-to-pole test results, as shown in Table V-78.

Table V-78
AIS-3 Abdomen Injuries Prevented

Vehicle Delta-V (mph)	Effectiveness	Target Population	Injuries Prevented
12-25	0.68 (at 20 mph)	23	16

The results in Table V-78 show that 16 AIS 3 abdominal injuries would be saved with thorax air bags.

As for the 252 AIS 1 and 88 AIS 2 injuries, since the corresponding effectiveness is not available, the benefits were not estimated. The revised injury distribution is shown in Table V-79

Table V-79
Revised Abdominal Injury Distribution for
Vehicle-to-Vehicle/others Side Crashes for
Occupant Represented by 50th Test Dummy

	AIS-3	AIS- 4	AIS-5	Fatality
Without Air bag	23	118	34	137
With deployed Air bag	7	118	34	137
Net Saved	16	0	0	0

The results in Table V-79 show that the HPS would prevent 16 AIS 3 abdominal injuries for all occupants when the 50th (ES-2) and 5th (SID-IIs) test dummies are used in the oblique pole test.

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

Pelvis: As discussed in the vehicle-to-pole crashes, due to limited test data and a lack of the AIS-1, -2, -5 and fatality injury probability curves, it was assumed that all pelvic injuries in vehicle-to-vehicle/others real world crashes are similar to the pelvic injuries predicted in vehicle-to-pole test crash environment.

For the 136 AIS-3 pelvic injuries, the benefits were calculated with the effectiveness derived from the vehicle-to-pole test results, as shown in Table V-80.

Table V-80
AIS-3 Pelvic Injuries Prevented in Vehicle-to-Vehicle/others

Vehicle Delta-V (mph)	Effectiveness	Target Population	Injuries Prevented
12-25	0.38 (at 20 mph)	136	52

The results in Table V-80 show that 52 AIS 3 injuries would be saved with a deployed air bag.

For all occupants, the results in Table V-80 show that the air bag would prevent 52 AIS-3 pelvic injuries when the 50th (ES-2) and 5th (SID-IIs) test dummies are used in the oblique pole test.

For the occupants represented by the SID-IIs 5th percentile test dummy, as discussed no benefit estimation was made.

For vehicle-to-vehicle/others, the analysis shows that head and thorax air bags would save 517 lives, 255 AIS-5, 381 AIS-4, 228 AIS-3 and 625 AIS 2 injuries, annually, when the proposed oblique pole test with the ES-2 and SID-IIs is adopted[43], as shown in Table V-81.

Table V-81
Overall Benefits for All Occupants in
Vehicle-to-Vehicle/Others In Side Crashes

Body region	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Head	-976	1069	20	208	247	438
Chest	-212	-212	191	164	3	66
Abdomen	0	0	16	0	0	0
Pelvis	0	0	52	0	0	0
Total	-1189	857	280	372	250	504

Benefit Derivation for the Complete Occupant Ejection

Although approximately 90% of the target population would be potentially affected by the proposed oblique pole tests for the 50th and 5th test dummies, combo and thorax air bags may not prevent occupants from ejection in side crashes. Thus, it was assumed that only curtain and the

[43] For the 517 lives saved, 438 are from head and 76 are from chest. For the 255 AIS 5 injuries, 251 are from head and 4 are from chest. For 381 AIS 4 injuries, 184 are from head and 196 are from chest. For 228 AIS 3 injuries, -58 are from head, 218 are from chest, 16 are from abdomen and 52 are from pelvis.

ITS air bags are effective in preventing occupants from ejection[44]. According to the air bag sales weight (per the 2003 head and side air bag systems), only 11% of vehicles would have either a curtain or ITS[45]. Accordingly, the population was further adjusted with the percentage for the occupants represented by a 50th percentile test dummy. In addition, since the target population was based on 19997-2002 CDS, 2001 FARS data, as shown in Table V-82, it was further adjusted with the 2003 safety belt usage rate.

Table V-82
Complete Occupant Ejection Based on 1997-2001
CDS, 2001 FARS Data

Body Region	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Head	0	195	29	12	11	400
Chest	0	0	12	0	0	230
Abdomen	0	0	0	0	18	6
Pelvis	0	0	0	0	0	0

The following derivation was made to adjust the 2001 data with the 2003 safety belt usage rate:

Table V-83
State Observed Safety Belt Usage Rate

Year	Usage Rate
1997	66.9%
1998	68.7%
1999	70.1%
2000	72.7%
2001	75.0%
2002	77.0%
2003	79.0%

The results in Table V-83 show that the overall belt use rate was 71.7% during the period from 1997 - 2002. For the 400 fatalities, the belt use rate among fatalities in potential fatal crashes

[44] See "Rollover Crash Worthiness Research," NHTSA, 2001 SAE Government Industry Meeting, http://www-nrd.nhtsa.dot.gov/PDF/nrd-01/SAE/SAE2001/Summers1.pdf. In addition, see "Rollover Ejection Mitigation Using An Infallible Tubular Structure (ITS)," 16th International Technical Conference on the Enhanced Safety of Vehicles, Paper Number 98-S8-W-18.

[45] According to the 2003 vehicles equipped with head & side air bags, approximately 7% are Curtain + Thorax, 3% are Curtain only and 1% are ITS + Thorax air bags. See Appendix A for additional discussion.

(UPFCs) is 54.2%[46]. Regarding safety belt effectiveness for fatal injuries, we estimated belts are 67.34% effective, based on that belts are 91% effective in prevent occupants from ejection and 74% effective in preventing belted occupants from being killed[47]. For the current 400 fatalities, the corresponding 364 potential fatalities were derived with the following equation:

Potential Fatality = (Current fatalities)/(1-UPFC*Effectiveness)

For the 2003 belt use rate, the following values were derived to determine potential lives saved by the higher safety use rate:

2003 Belt Use Rate:	79.0%
Belt Effectiveness:	67.34%
Potential Fatalities:	640
Lives Saved by Higher Rate:	36

For the nonfatal head injuries, the injury reduction was derived based on the equation above and also weighted injury frequency, as shown in Tables V-84 and 85.

Table V-84
Head Injuries Prevented by Higher Belt Use Rate

	Frequency
Total nonfatal Injuries	247
Potential non-fatalities	478
Current Fatalities Prevented by belt	231
Fatalities Prevented by Higher Rate	254
Net saved at Higher Rate	23

[46] See "Belt Use Regression Model – 2003 Update," by J. Wang and L. Blincoe, The Office of Planning, Evaluation, and Budge, Department of Transportation.

[47] An estimated 74 percent of ejection fatalities would have survived if they had remained within their vehicle. (Also, see Kahane, Charles J., An Evaluation of Door Locks and Roof Crash Resistance of Passenger Cars, NHTSA Publication No. DOT HS 807 489, Washington, 1989.) FARS data suggest that 3-point belts reduce the probability of ejection by at least 91 percent in fatal crashes in cars and also in light trucks.

The net saved in Table V-84 were distributed according to the weighted injury frequency, as shown in Table V-85.

Table V-85
Complete Occupant Ejection Adjusted with
2003 Safety Belt Usage Rate

Body Region	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Head	0	177	26	11	10	364
Chest	0	0	12	0	0	230
Abdomen	0	0	0	0	18	6
Pelvis	0	0	0	0	0	0

The adjusted target population adjusted for occupants represented by a 50th percentile male test dummy, for the complete occupant ejection case, is shown in Table V-86:

Table V-86
Complete Occupant Ejection Injuries in Side Crashes
(Adjusted with minimum air bag size, impact angle & 50th test dummy)

Body Region	Injury Level					
	MAIS-1	MAIS-2	MAIS-3	MAIS-4	MAIS-5	Fatality
Head and Face	0	104	15	6	6	212
Thorax	0	0	7	0	0	135
Abdomen	0	0	0	0	7	2
Pelvis	0	0	0	0	0	0

Head: The results in Table V-86 show that the occupants had a high fatality rate, resulting from head injuries when compared to other crash modes such as vehicle-to-vehicle/others or vehicle-to-pole crashes. To investigate severity of the head injuries further, percent injury distribution of the occupant ejection injuries was compared to the distribution of the vehicle-to-pole crashes, as shown in Table V-87 and Figure V-7.

Table V-87
Percent Head Injury Distribution of Occupant Ejection and Vehicle-to-Pole Crashes (50th)

Crash Mode		MAIS-1	MAIS-2	MAIS-3	MAIS-4	MAIS-5	Fatality	Total
Occupant Ejection	Frequency	0	104	15	6	6	212	343
	% Head Injury	0%	30%	4%	2%	2%	62%	100%
Vehicle-to-Pole	Frequency	799	256	10	23	63	183	1,334
	% Head Injury	60%	19%	1%	2%	4%	14%	100%

The results in Table V-87 show that, unlike the vehicle-to-pole side crashes, the majority of the occupant ejection injuries are either fatalities or AIS 2 injuries.

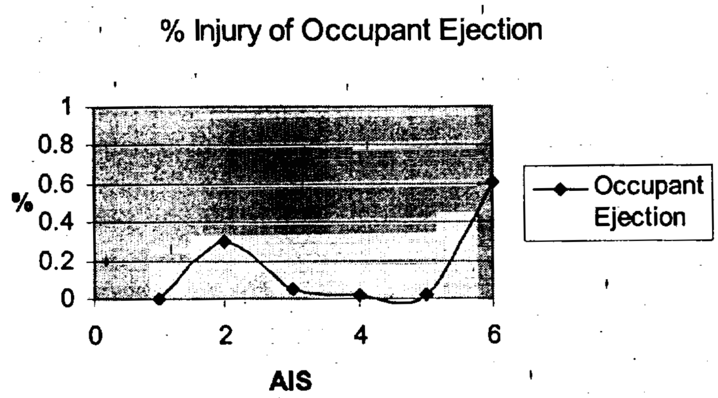


Figure V-7. Percent Head Injury Distribution of Occupant Ejection

The plot in Figure V-7 shows there are two distinctive peaks: at AIS 2 and fatality. According to the head injury probability distribution, there is a highest probability of AIS 2 injuries (41%) at a HIC of 850. At this HIC level, approximately 87% of all injuries would be either AIS 1, 2 or 3 injuries. According to the head impacts with vehicle interior component case, a HIC of 920 would be measured at a vehicle delta-V of 20 mph. At this HIC level (HIC = 920), approximately 84% of all injuries would be either AIS 1, 2 or 3 injuries. Based on these percent injury probability scores (87% and 84%), it was determined that the minor head injuries in occupant complete ejection crashes, such as AIS 2 injuries, occurred when the head of an occupant impacts with external objects that have a similar stiffness of the vehicle interior components or when the head impacts have a long impact duration (in other words, the head/occupant slides during impact).

For the complete ejection benefit analysis, it was assumed that all fatalities are resulting from head-to-pole/tree impacts and that all AIS 2, 3 and 4 are resulting from the head impacts with exterior objects that have the same rigidity of vehicle interior components. In addition, due to limited data, only head nonfatal and fatal injuries were considered for the complete occupant ejection case. For the 2003 curtain and ITS distribution rate (of 11%), the occupant ejection benefits were derived, as shown in Table V-88 and 89.

Table V-88
Head Injuries Prevented and Lives Saved in Complete Occupant Ejection Side Crashes for Occupant Represented by 50th Percentile Male Test Dummy

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Population with 11%	0	12	2	1	1	24
Benefits	0	9	1	0	1	24

Table V-89
Overall Head Benefits Adjusted with Redistribution of the lives Saved and Injuries Prevented for Occupant Represented by 50th Percentile Male Test Dummy, with 11%

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Benefits	-13	5	0	0	1	24

The results in Table V-89 show that the ITS and curtain head air bags with the 11% distribution rate would save 24 lives and prevent 1 AIS 5 and 5 AIS 2 injuries for occupants represented by a

50th percentile male test dummy. However, these head air bags would increase 13 AIS 1 injuries, annually.

If all vehicles were equipped with curtain air bags (i.e., 100% distribution rate), the occupant ejection benefits would substantially increase, as shown in Tables V-90 and 91.

Table V-90
Head Injuries Prevented and Lives Saved in Complete Occupant Ejection Side Crashes for Occupant Represented by 50th Percentile Male Test Dummy with 100%

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Population with 100%	0	104	15	6	6	213
Benefits	0	82	13	6	6	213

Table V-91
Overall Head Benefits Adjusted with Redistribution of the lives Saved and Injuries Prevented for Occupant Represented by 50th Percentile Male Test Dummy with 100%

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Benefits	-116	45	0	3	6	213

The results in Tables V-90 and 91 show that when all vehicles are equipped with curtain air bags, curtain air bags would save 213 additional lives, annually, as shown in Table V-92.

Table V-92
Benefits If All Vehicle are Equipped with Curtain Air Bag for Occupant Represented by 50th Percentile Male Test Dummy with 100%

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Benefits	-116	45	0	3	6	213

For the occupants represented by the SID-IIs 5th percentile test dummy, the target population was adjusted with the 90% for the occupants represented by the 5th percentile female test dummy, as shown in Table V-93.

Table V-93
Complete Occupant Ejection Injuries in Side Crashes
(Adjusted with minimum air bag size, impact angle & 5th test dummy)

Body Region	Injury Level					
	MAIS-1	MAIS-2	MAIS-3	MAIS-4	MAIS-5	Fatality
Head and Face	0	56	8	3	3	116
Thorax	0	0	4	0	0	72
Abdomen	0	0	0	0	4	1
Pelvis	0	0	0	0	0	0

Similar to the methodology used for the 50th percentile occupants, head benefits for occupants represented by a 5th percentile female test dummy in complete occupant ejection side crashes were derived, as shown in Tables V-94 and 95.

Table V-94
Head Injuries Prevented and Lives Saved in Complete Occupant Ejection Side Crashes for Occupant Represented by 5th Percentile Female Test Dummy with 11%

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Population with 11%	0	6	1	0	0	13
Benefits	0	5	1	0	0	13

Table V-95
Overall Head Benefits Adjusted with Redistribution of the lives Saved and Injuries Prevented for Occupant Represented by 5th Percentile Female Test Dummy with 11%

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Benefits	-7	3	0	0	0	13

The results in Table V-95 show that the ITS and curtain head air bags would save 13 lives for occupants represented by a 5th percentile male test dummy. However, these head air bags would increase 3 AIS 2 and 7 AIS 1 injuries, annually.

If all vehicles were equipped with curtain air bags (i.e., 100% distribution rate), the benefits would increase, as shown in Table V-96.

Table V-96
Head Injuries Prevented and Lives Saved in Complete Occupant Ejection Side Crashes for Occupant Represented by 5th Percentile Male Test Dummy with 100%

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Population with 100%	0	56	8	3	3	115
Benefits	0	44	6	3	3	115

Table V-97
Overall Head Benefits Adjusted with Redistribution of the lives Saved and Injuries Prevented for Occupant Represented by 5th Percentile Male Test Dummy with 100%

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Benefits	-62	24	0	2	3	115

The results in Tables V-96 and 97 show that when all vehicles are equipped with curtain air bags, curtain air bags would save 115 additional lives, annually, as shown in Table V-98.

Table V-98
Benefits If All Vehicle are Equipped with Curtain Air Bag for Occupant Represented by 5th Percentile Male Test Dummy with 100%

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Benefits	-62	24	0	2	3	115

The revised injury distributions were combined to derive the net benefit for head injuries in complete occupant ejection crashes for all occupants when the 50th (ES-2) and 5th (SID-IIs) dummies are used in the oblique pole test, as shown in Table V-99

Table V-99
Lives Saved and Injuries Prevented for All Head Injuries Affected by Head Air Bags in Complete Occupant Ejection Crashes

Occupants	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
50th with 11%	-13	5	0	0	1	24
5th with 11%	-7	3	0	0	0	13
Total with 11%	-20	8	0	1	1	37
50th with 100%	-116	45	0	3	6	213
5th with 100%	-62	24	0	2	3	115
Total with 100%	-179	70	1	5	9	328
Increase, with 50th	-103	40	0	3	5	189
Increase, with 5th	-55	21	0	2	3	102
Total Increase	-158	62	1	5	8	291

When the results in Table V-99 that if all vehicle were equipped with curtain air bags, the bags would save additional 291 lives, 8 AIS-5, 5 AIS 4, 1 AIS 3 and 62 AIS 2 injuries, but the redistribution of these injuries would result in an increase of 158 AIS 1 injuries in complete occupant ejection side crashes when the proposed oblique pole test with the ES-2 and SID-IIs is adopted.

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-100

Table V-100
Overall Benefits of Head and Thorax/Side Air Bags for
All Occupants in All Side Crashes

Crashes	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Vehicle-to-Pole/Tree	-227	127	-17	23	76	261
Vehicle-to-vehicle/Others	-1212	833	283	402	250	516
Complete Occupant Ejection*	-20	8	0	0	1	37
Total	-1459	968	267	426	328	813

* With the 2003 Curtain and ITS distribution rate.

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 HPS and also the compliance rate of HPS. For the adjustment, individual HPS 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.

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-101.

Table V-101
ES-2 Oblique Pole Test Compliance Rate

Test Vehicle	Body Region			
	Head	**Chest**	**Abdomen**	**Pelvis**
2002 Saab	P	F	P	P
1999 Volvo S80	P	P	P	P
2001 Saturn	P	F	P	P
1999 Nissan Maxima	F	P	P	P
2002 Ford Explorer	P	F	F	P
1999 Volvo S80[48]	P	F	P	P
2000 Saab	P	F	P	P
2004 Honda Accord	P	P	P	P
2004 Toyota Camry	P	F	P	P
Passing Rate	89%	33%	89%	100%
Failure Rate	11%	66%	11%	0%

P: Pass, F: fail

[48] The 214 seating procedure was used for the 1999 Volvo S80, 2000 Saab, 2004 Honda Accord, 2004 Toyota Camry

Vehicles equipped with head and side air bags and its distribution are shown in Table V-102 and 103.

Table V-102
Absolute Values for Passenger Cars and Light Trucks for All Bbody Types

	1999	2000	2001	2002	2003	Total
Thorax only	1,169,523	1,884,592	1,987,546	3,238,854	1,827,739	10,108,254
AC + Thorax	98,241	126,436	664,973	990,382	1,180,414	3,060,447
Combo	251,887	783,171	1,278,710	1,250,147	1,287,874	4,851,789
AC Only	0	0	38,328	170,081	520,028	728,437
ITS + Thorax	122,973	155,675	198,895	213,726	237,418	928,687
Total	1,642,624	2,949,874	4,168,452	5,863,190	5,053,473	19,677,613

Table V-103
Distribution of Head and Thorax Air Bags (up to 2003 estimated sales)

	1999	2000	2001	2002	2003	Avg.
Head Protection Only	0.00%	0.00%	0.23%	0.99%	3.02%	0.85%
Thorax Protection Only	7.00%	10.73%	11.99%	18.80%	10.61%	11.85%
Head and Thorax Protection	2.83%	6.06%	12.93%	14.25%	15.71%	10.36%
Total	9.83%	16.79%	25.15%	34.04%	29.33%	23.07%

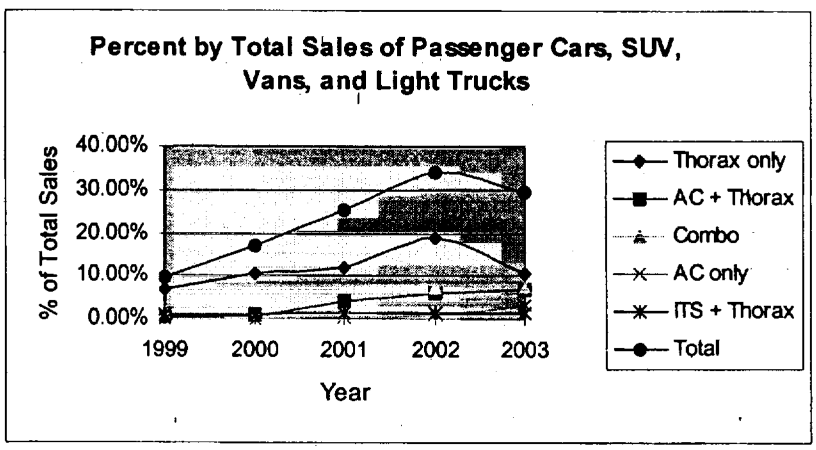


Figure V-8. Distribution of Head and Thorax Bags vs. Year

Since only the 50th test dummy was considered for the compliance rate derivation in the oblique pole test and the pole test data do not clearly show whether the existing HPS would meet the requirements with the 5th test dummy, the derived benefits were adjusted with the number of occupants represented by the 50th test dummy. According to the 1997-2001 NASS CDS, 65% of all injured occupants were in the 50th category. In addition, the benefits resulting from the vehicle-to-pole, vehicle-to-vehicle/others and complete occupant ejection were adjusted with the number of current vehicles equipped with head& side air bags[49], passing rate and the percent of 50th occupants, as shown in Tables V-104 to -107.

Table V-104
Benefits Adjusted with Number of Vehicles
Equipped with HPS – for **Head** Injury

	AIS 1	**AIS 2**	**AIS 3**	**AIS 4**	**AIS 5**	**Fatality**
Additional Benefits	-1072	1079	1	202	291	625

Table V-105
Benefits Adjusted with Number of Vehicles Equipped with HPS – for **Chest** Injury

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Additional Benefits	-232	-232	185	189	3	88

Table V-106
Benefits Adjusted with Number of Vehicles Equipped with HPS – for **Abdominal** Injury

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Additional Benefits	0	0	0	0	0	0

Table V-107
Benefits Adjusted with Number of Vehicles Equipped with HPS – for **Pelvic** Injury

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Additional Benefits	0	0	45	0	0	0

[49] Based on the 2003 data.

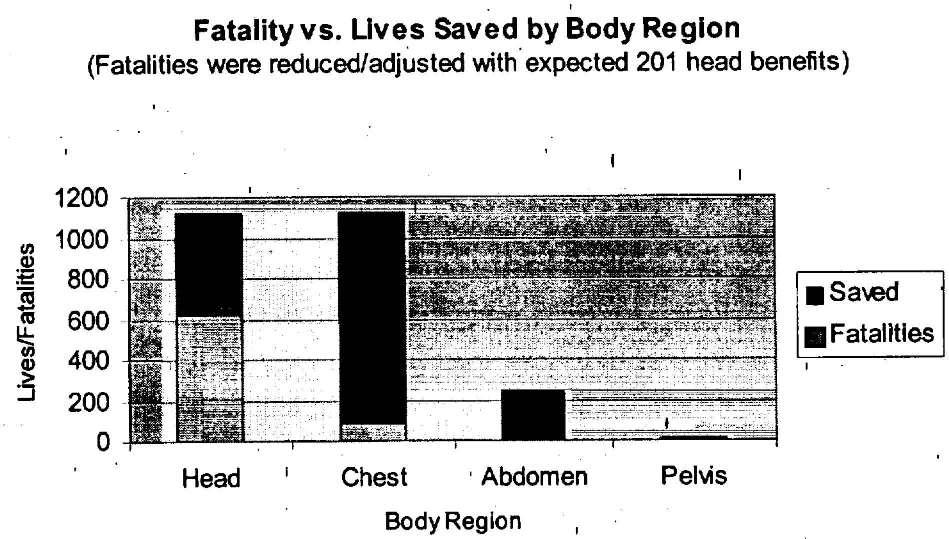


Figure V-9. Lives Saved vs. Body Injury Region
(with the 2003 air bag distribution rate)

The benefit estimation shows that if all HPS meet the proposed pole test (for 50th and 5th test dummies) and that the 11% curtain and ITS distribution remains unchanged, head & side air bags would save 813 lives annually. Regarding <u>additional</u> lives saved and injuries prevented, head & side airbags would save 713 <u>additional</u> lives and prevent 292 AIS-5, 390 AIS-4, 230 AIS-3 and 847 AIS 2 <u>additional</u> injuries annually. If all vehicles were equipped with curtain air bags, the occupant ejection benefits would increase substantially, as shown below. The unadjusted and additional benefits are summarized in Tables V-108 - 110.

Table V-108
Summary of Target Population (for head, chest, abdomen and pelvis <u>only</u>)

	Pole/Tree Impacts	Vehicle-to-Vehicle/Other Road Side Objects	Non-Rollover Complete Ejections*	Total
Fatality	460	1435	600	2495
AIS 5	94	394	28	516
AIS 4	197	2288	11	2496
AIS 3	90	2713	38	2841
AIS 2	437	3235	177	3849
AIS 1	1389	18170	0	19559

* Adjusted with the 2003 safety belt use rate.

Table V-109
Annual Lives Saved and Injuries Prevented by Head & Side Air Bags in Vehicle-to-Pole, Vehicle-to-Vehicle/Other Road Side Objects & Non-Rollover Complete Occupant Ejection

	Pole/Tree Impacts	Vehicle-to-Vehicle/Other Road Side Objects	Non-Rollover Complete Ejections	Total
Fatality	261	504	328	1093
AIS 5	76	250	9	335
AIS 4	23	372	5	400
AIS 3	-17	263	1	257
AIS 2	127	857	70	1054
AIS 1	-227	-1188	-179	-1594

Table V-110.
Maximum Additional Lives Saved and Injuries Prevented in Vehicle-to-Pole and Vehicle-to-Vehicle/Other Road Side Objects & Non-Rollover Complete Ejection[50]

	Pole/Tree Impacts	Vehicle-to-Vehicle/Other Road Side Objects	Non-Rollover Complete Ejections	Total
Fatality	233	453	306	992
AIS 5	69	225	8	299
AIS 4	21	340	4	366
AIS 3	-15	242	1	228
AIS 2	112	753	65	930
AIS 1	-203	-1071	-167	-1441

Overall Distribution of Lives Saved and Injuries Prevented: As discussed briefly in the vehicle-to-pole benefit section, the lives saved and injuries would result in less severe non-fatal injuries or no-injury, as shown in Table V-111.

Table V-111
Net Increase in Injury for Each Injury Level With Curtain Head and Thorax Air Bags (100% distribution rate)

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Net Benefits	-1441	930	228	366	299	992

[50] See Tables V-118, -119 and -120 for the combination with 2 sensors, curtain with 2 sensors and curtain with 4 sensors, respectively.

Surveillance of Current Head and Side Air Bags: In August 2003, IIHS published[51] a statistical analysis based on driver only fatalities in passenger cars[52] 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 RF 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.

We have extended the IIHS sample by:

- Including calendar year 2002 FARS data
- Including right-front passengers (nearside = 2-4:00) as well as drivers.
- Extending the control group to include farside impacts (i.e., 1-5:00 for drivers, 7-11:00 for RF passengers) as well as 12:00 and 6:00 impacts.

These resulted in three times as much data as the IIHS study.

Through 2002 FARS, there are 358 records of drivers or right-front passengers in passenger cars who died in nearside-impact crashes and were in seats equipped with side-impact torso air bags. Of these, 121 also had a head air bag, either as part of a combination air bag with chambers for the torso and the head (67), or as a separate roof-rail-mounted curtain or inflatable tubular structure (54).

[51] "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.
[52] 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.

	Nearside	Non-Nearside	Ratio	Fatality Reduction
Without side air bags	3,720	8,345	.446	
With torso-only bags	237	517	.458	– 3 %
With head+torso bags	121	352	.344	23 %

The 23 percent reduction of nearside fatalities for head+torso air bags, relative to no side air bags is statistically significant at the .05 level (chi-square = 5.91). The observed –3 percent effect for torso-only air bags is not statistically significant (chi-square = 0.12), but it suggests the overall effect of torso-only bags is not going to be very large.

Currently there are too few data to determine whether there is a difference in effectiveness between the combination torso/head air bags and the separate window curtains or inflatable tubular structure. Based on data available, all of the systems are close to the 23 percent overall effectiveness.

Based on our 2001 FARS target population of 5,225[53] near side front outboard occupant fatalities in passenger cars and light trucks, a 23 percent effectiveness rate would indicate that these countermeasures could save 1,202 fatalities[54] per year (5,225*.23). This assumes that these countermeasures are as effective for light trucks as they are for passenger cars.

These preliminary findings indicate a fantastic benefit for these head air bags. Theoretically, the effectiveness of these air bags can be improved. We have found in our testing that some air bags did not deploy in an angular impact and that some air bags did not provide enough coverage for

[53] Includes 4,523 cases with no rollover and 702 cases with rollover as a subsequent event in the crash.
[54] Due to limited data, the expected FMVSS No. 201 interior padding head benefits were not excluded for the estimated 1,202 lives saved.

the head in some angular impacts. Furthermore, we believe that the chest and abdomen could be better protected. Finally, none of these passenger car air bags were designed to deploy in a rollover crash. 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 conceivable that an AC HPS designed to meet the proposed performance provides some protection for occupants in rear outboard seating positions if the air bags are design to deploy when the vehicle is impacted at the rear door or the C-pillar.

According to 1997 –2001, NASS CDS annualized crash data for rear outboard MAIS-1+ injuries, 4,514 all injuries occurred annually in vehicle-to-pole, vehicle-to-vehicle/others and complete ejection. Among these injuries, 1,441 are head and facial injuries, as shown in Table V-113.

Table V-113
Head & Face Injuries of Rear Outboard Occupant, 1997-2001 NASS CDS

Injury	MAIS-1	MAIS-2	MAIS-3	MAIS-4	MAIS-5	Fatality	Total
Head & Face	1000	144	91	116	10	80	1,441
Percent	69%	10%	6%	8%	0.7%	6%	100%

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 do not cover the C-pillar and that air bags are big enough to protect occupants represented by a 5th percentile female test dummy. According to the curtain air bag relative percentage[55], 4 lives and 1 AIS 5, 9 AIS 4, 6 AIS 3, 5 AIS 2 injuries would be saved and prevented, respectively, as shown in Table V-114.

Table V-114
Overall Head and Facial Benefits for Occupants in Rear Outboard Seating Positions (with 9.87% Distribution Rate)

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Vehicle-to-Pole/Tree	-2	-1	4	0	0	1
Vehicle-to-Vehicle	-9	7	3	7	0	2
Complete Occupant Ejection	-2	-1	0	1	1	2
Total	-12	5	6	9	1	4

If all vehicles were equipped with curtain air bags, curtain air bag would save 44 lives for occupants in real outboard seating positions, as shown in Tables V-115 and 116.

Table V-115
Overall Head and Facial Benefits for Occupants in Rear Outboard Seating Positions (with assumed 100% Distribution Rate)

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Vehicle-to-Pole/Tree	-19	-8	43	-1	0	6
Vehicle-to-Vehicle	-91	67	26	76	0	21
Complete Occupant Ejection	-15	-10	-4	11	9	17
Total	-125	49	65	86	0	44

Table V- 116
Additional Head and Facial Benefits for Occupants in Rear Outboard Seating Positions
(With assumed 100% vs. 9.87% Curtain Distribution Rates)

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Vehicle-to-Pole/Tree	-17	-7	39	-1	0	5
Vehicle-to-Vehicle	-82	61	24	68	0	19
Complete Occupant Ejection	-14	-9	-4	10	8	16
Total	-113	45	59	77	8	40

[55] For the absolute and relative distributions, see Tables V-102 and V-103, respectively.

(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. However, the agency has not tested these countermeasures in 25 mph pole tests or higher speed pole tests. Thus, the agency does not know how the effectiveness of the countermeasures decreases as test speed increases. In the Preliminary Economic 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.). We know that there will be a drop off in effectiveness as delta-V gets higher and the air bag bottoms out. However, we don't know where that is, or how much it might change between manufacturer's designs. Since bottoming-out speed for each body region is critical in determining benefits, the benefit estimation should be revised when additional data are available.

(3) Crashes Involving Rollover: Rollover is a complex event, heavily influenced by vehicle properties, driver and road characteristics. A recent study of NASS CDS data estimated that while over 13 percent of rollovers in single-vehicle crashes occur on-road or on a paved shoulder, only 4.2 percent are un-tripped. (See Docket: NHTSA –2000-6859 RIN 2127-AC64.) Unlike other vehicle crashes, generally NASS and FARS databases do not report vehicle delta-Vs or the number of rolls, 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 vehicle's 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 735 drivers and 258 front outboard passengers would be saved, as shown below:

Table V-117
Driver and Front Outboard Passengers Saved by Curtain and Thorax Air Bags
(if all vehicles are equipped with Curtain and thorax air bags)

	AIS 1	**AIS 2**	**AIS 3**	**AIS 4**	**AIS 5**	**Fatality**
Overall	-1352	603	144	366	303	993
Driver	-1000	446	107	271	224	735
Front Passenger	-352	157	37	95	79	258

F. Benefits vs. Air Bag System

Since vehicle manufacturers would use different types of head and thorax air bag systems to comply with the proposed requirements, the overall benefits would be affected by air bag type. We estimated benefits for three different systems: 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 118 – 120.

Table V-118
Combination Head/Thorax Side Air Bag with Two Sensors

Occupants	**Crash**	**AIS 1**	**AIS 2**	**AIS 3**	**AIS 4**	**AIS 5**	**Fatal**
Front	Vehicle-to-Pole	-203	112	-15	21	68	233
Front	Vehicle-to-Vehicle	-1071	753	242	340	223	453
Total Benefit		-1274	865	227	362	291	686

Table V-119
Window Curtain + Thorax Air Bags with Two Sensors

Occupants	Crash	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatal
Front	Vehicle-to-Pole	-203	112	-15	21	68	233
Front	Vehicle-to-Vehicle	-1071	753	242	340	223	453
Front	Complete Ejection	-167	65	1	4	8	306
Rear	Vehicle-to-Vehicle	-82	61	24	68	0	19
Rear	Complete Ejection	-14	-9	-4	10	8	16
Total Benefit		-1537	982	248	444	307	1027

Table V-120
Window Curtain + Thorax Air Bags with Four Sensors

Occupants	Crash	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatal
Front	Vehicle-to-Pole	-203	112	-15	21	69	233
Front	Vehicle-to-Vehicle	-1071	753	242	340	223	453
Front	Complete Ejection	-167	65	1	4	8	306
Rear	Vehicle-to-Pole	-17	-7	39	-1	0	5
Rear	Vehicle-to-Vehicle	-82	61	24	68	0	19
Rear	Complete Ejection	-14	-9	-4	10	8	16
Total Benefit		-1554	975	287	443	317	1032

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 injuried without air bags when the head impacts with a pole at 20 mph.

With the lognormal distribution curves, we estimated that combo air bags would save 684 lives and prevent 1,000 serious injuries, annually, as shown in Table V-121[56]:

Table V-121. Benefits Estimated with Lognormal Risk Distribution

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatality
Combo air bag with 2 sensors	-1,825	1,017	290	408	302	684
Curtain + thorax with 2 sensors	-2,246	1,168	321	505	318	1,022
Curtain + thorax with 4 sensors	-2,276	1,164	365	505	318	1,027

The results in Table V-121 show that when the lognormal distribution curves were used, the estimated fatal benefits decreased from 686 to 684 for the combo system and from 1,027 to 1,022 for the curtain with 2 sensors, and finally from 1,032 to 1,027 for the curtain with 4 sensors[57]. However, the AIS 3 – 5 benefits increased from 880 to 1,000 for the combo, from 999 to 1,144 for the curtain with 2 sensors and from 1,037 to 1,188 for the curtain with four sensors.

[56] Based on the individual injury risk probability in Table III-3, Final Economic Assessment, FMVSS No. 208, Advanced Air Bags, Office of Regulatory Analysis & Evaluation, Plan and Policy, NHTSA, May 2000. A linear approximation was used to estimate the head injury risk for a given HIC when the HIC level is not in the table.
[57] Similar to the benefits with the Prasad/Mertz, the expected 201 interior head protection benefits and the benefits resulting from the 2003 safety belt use rate were not included.

Appendix A.

HPS Performance Estimation with Sales Weighted Cumulative Percentage

The adjusted HPS performance for <u>each</u> injured body region (i.e., for head, abdomen, chest and pelvis) is derived from the sales weighted cumulative percentage of the entire HPS tested and relative performance of different types of HPS. The percentage point reduction, in terms of injury measurement score, for each HPS tested is applicable only to the proportion that each HPS represents within the tests. In other words, by assuming that the proportion of each HPS tested is the head air bags' proportion of on-road exposure, the reduction percentage is weighted by the HPS's sales volume. (Note that due to limited data, vehicle model was not considered for the analysis. In other words, under this methodology, a particular HPS produces the same dummy responses at a given delta-V regardless of vehicle model/type.) The relative performance is defined as performance of each HPS type in the identical test condition if all HPS types were tested. (For example, assume only Air Curtain (AC) and Combo HPS are tested during a 18 mph pole test, where the AC HPS produces HIC of 700 and the Combo HPS produces HIC of 800 during the test. Further, assume the relative performance of AC vs. Combo vs. ITS is 7:8:9 at 18 mph, in terms of HIC score. Then, if the ITS were tested, it would produce HIC of 900. Further, assume that AC, Combo and ITS have 52.7% (=[1,180,414+520,028]/3,225,734), 39.9% (=1,287,874/3,225,734) and 7.4% (=237,418/3,225,734) sales volume, respectively. Then, the performance adjusted and sales weighted HIC would be: (700 x 0.527 $_{\text{AC sales volume}}$) + (800 x 0.399 $_{\text{Combo sales volume}}$) + (900 x 0.074 $_{\text{ITS sales volume}}$) = 369 + 319 + 67 = 755. Thus, the (hypothetical) production HPS would produce a HIC of 755 during the pole test. As illustrated, the adjusted and weighted performance[58] is calculated using the following formula:

[58] Although the weighting is only applicable to the measured values at the tested speeds (of 18 mph and 20 mph) because the data were only collected at vehicle delta-V of 18 mph and 20 mph, it was assumed that the weighting is applicable to all impact speed in the operating range.

$M = \Sigma (w_i \times m_i)$

Where M: adjusted and weighted performance of each HPS

w_i: the proportion of the head air bag's sale to the sales of all the HPS tested.

m_i: Relative performance of each HPS

The side impact air bags sales volume was estimated based on 2003 Buying a Safer Car and 2002 Wards sales data and is presented in Table A-1; 2002 sales data were used as a proxy for 2003 sales, since 2003 data is still not yet available. For vehicles that have head and/or thorax air bags as an option, a 20% installation rate was assumed.

Table A-1. Estimated Side Air bags[59] in 2003 Compact, Light, Medium, Heavy Passenger Cars and Light Trucks, SUV's, and Vans.

Absolute Values for Passenger Cars and Light Trucks							
		1999	2000	2001	2002	2003	Total
All Body Types	Thorax only	1,169,523	1,884,592	1,987,546	3,238,854	1,827,739	10,108,253
	AC + Thorax	98,241	126,436	664,973	990,382	1,180,414	3,060,447
	Combo	251,887	783,171	1,278,710	1,250,147	1,287,874	4,851,789
	AC only	0	0	38,328	170,081	520,028	728,437
	ITS + Thorax	122,973	155,675	198,895	213,726	237,418	928,687
		1,642,624	2,949,874	4,168,452	5,863,190	5,053,473	19,677,613

	1999	2000	2001	2002	2003	Total
Head Protection Only	0	0	38,328	170,081	520,028	728,437
Thorax Protection Only	1,169,523	1,884,592	1,987,546	3,238,854	1,827,739	10,108,253
Head and Thorax Protection	473,101	1,065,282	2,142,578	2,454,255	2,705,706	8,840,923
	1,642,624	2,949,874	4,168,452	5,863,190	5,053,473	19,677,613

Based on the sales volume, Sales Weight Factor, w_i for each type of HPS was derived, as shown in Table A-2. (See Appendix D for the derivation.)

[59] Include combo air bags. Combo air bags were included in "front side air bags" and also "head air bags" categories.

Table A-2. Sales Weight Factor, w_i for Each Type of Head Air bag

Head Protection System	Sales Weight Factor
Combo (i.e., Integrated)	0.399
Curtain (AC)	0.161
Curtain (AC) + Thorax (Th)	0.366
ITS	0.00
ITS + Thorax (Th)	0.074

Appendix B.

Head and Side Air Bag Hypothetical Case Study

1. Hypothetical Cases

Since each target population group consists of various crash modes, several hypothetical side crash cases were examined to determine severity of the injuries. For example, in some vehicle-to-pole crash cases, the head of an occupant impacts with a pole or tree, on the other hand, the head might impact with the vehicle interior components or completely avoid any physical contact. The following hypothetical cases were examined to determine characteristics of the head injuries.

2. Impact of Pole Tests

2.1 Impact of FMVSS No. 201 Optional Pole Test (i.e., 18 mph perpendicular) with SID-H3.

This section estimated the safety impacts of head protection systems (HPS) that are designed to meet the 18 mph perpendicular pole test. Benefit estimates were derived based on the production HPS. (Note that the "production HPS" is based on the HPS systems tested in the NHTSA pole tests and other related tests.)

2.1.1 Side Crashes Involving Occupant Head Impacts with Narrow Objects:

Head injuries: Since the pole (sled) tests were performed at specific delta-V's (i.e., 18 mph and 20 mph), HPS performance for impact speeds other than the test speeds were estimated with a series of pendulum tests performed by Volvo & Autoliv to derive HIC scores that would be measured with the SID-H3 test dummy in the air bag operating range. (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.) 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)[60]. The pendulum test results are duplicated in Figure B-1.

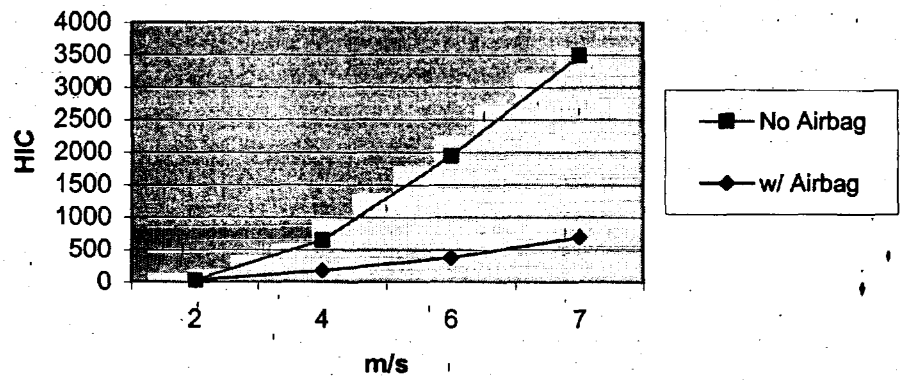


Figure B-1. Pendulum Test: HIC vs. Impact Velocity (with 55 mm cell thickness, Air Curtain)

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). For the hypothetical case study, therefore, it was assumed that HPS bottoms out (i.e., deflates) at a vehicle delta-V of 20 mph.

---

[60] 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.

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 the pendulum HIC measurement made with the head-form at the same impact speed. To reflect these factors, the pendulum 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:

$$\text{Full Dummy HIC} = 0.75446\ (\text{FMH HIC}) + 166.4$$

In addition[61], 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 converted baseline and "deployed" HIC scores are shown in Table B-1.

[61] Note that the FMH impactor (head-form) used to derive the formula weights 4.5 kg (10 lbs) has a diameter of about 5 inches. Although kinetic energy associated with the 6.8 kg head-form used in the pendulum test is 44 percent higher compared to the FMVSS No. 201 head-form, due to the limited test data, the formula was used as a proxy for the conversion. If the 4.5 kg head-form were used, the air bag would be bottomed out at a higher impact speed.

Table B-1
Estimated HIC Values for Inflatable Curtain (AC) Head Air Bag

Pendulum Speed	Occupant Delta-V	Vehicle Delta-V	Pendulum Baseline HIC	Pendulum AC HIC	Full Dummy Baseline HIC[1]	Full Dummy AC HIC[2]
2 m/s	4.5 mph	6 mph	30	25	189	185
4 m/s	8.9 mph	12 mph	650	150	657	302
4.8 m/s	10.8 mph	14 mph	1320	200	1162	317
5.16 m/s	11.54mph	15 mph	1404	296	1226	390
5.5 m/s	12.3 mph	16 mph	1625	330	1392	415
6 m/s	13.4 mph	17 mph	1950	380	1638	453
6.2 m/s	13.8 mph	18 mph	2260	444	1871	501
6.9 m/s	15.4 mph	20 mph	3345	668	2690	670
7 m/s	15.7 mph	20.4 mph	3500	700	2807	694

1. $HIC(Dv)_{Baseline} = (650)Dv - 1950$, for 4 m/s to 6 m/s pendulum speed and $HIC(Dv)_{Baseline} = (1550)Dv - 7350$ for 6 m/s to 7 m/s pendulum speed.
2. $HIC(Dv)_{Deployed} = (100)Dv - 220$, for 4 m/s to 6 m/s pendulum speed and $HIC(Dv)_{Deployed} = (320)Dv - 1540$ for 6 m/s to 7 m/s pendulum speed.

Since the results in Table B-1 are based on a particular air bag design (i.e., Inflatable Curtain/Air Curtain (AC)) in a controlled test environment, an adjustment was made to reflect effects of real world crashes by comparing the full dummy test results (based on the pendulum test results) with the pole test results. The full dummy HIC scores and the estimated HIC scores for the pole (sled) tests with the SID-H3 test dummy are shown in Table B-2.

Table B-2
HIC Scores Resulting from Pendulum and Pole Tests (with SID-H3)

Occupant Delta-V (mph)	Vehicle Delta-V (mph)	Full Dummy Baseline AC HIC	Full Dummy Deployed AC HIC	Pole Test (Average) Baseline HPS HIC	Pole Test Average "Deployed" HPS HIC	Pole Test Sales weighted "Deployed" HPS HIC
4.5	6	189	185	No data	No data	No data
8.9	12	657	302	No data	No data	No data
11.5	15	1226	390	No data	No data	No data
12.3	16	1392	415	No data	No data	No data
13.4	17	1638	468	No data	No data	No data
13.8	18	1871	592	10,152	360	311
15.4	20	2690	602	7,493*	330*	238*

* These HIC scores were not used for the analysis.

Note that the results in Table B-2 show that the baseline and "deployed" HIC scores resulting from the pole test are different from the corresponding full dummy HIC scores. We suspect that high rigidity and sharp surface contour of the pole could contribute to the high baseline HIC scores. As for the lower "deployed" pole HIC scores, it is possible that the overall operating pressure (i.e., internal pressure) of the air bags used in the pole test could be lower than the air bag operating pressure used in the pendulum test. As stated in the pendulum test report, lower operating pressure would reduce the "deployed" HIC scores.

By comparing HIC scores at a vehicle delta-V of 18 mph, it was determined that the baseline HIC score resulting from the sled pole tests is 5.43 times higher than the baseline full dummy HIC score resulting from the pendulum test. However, the "deployed" HIC score resulting from the (sled) pole tests is 1.64 times lower than the "deployed" full dummy HIC score (that was derived from the pendulum test). Due to limited data, it was assumed that these factors were constant over the entire air bag operating delta-V range. Accordingly, the factors were applied to the full dummy HIC profiles to estimate the corresponding pole test HIC scores, with respect to vehicle delta-V, as shown in Table B-3.

Table B-3
Pendulum and Average HIC Scores Resulting from Pole Test
(Adjusted with two factors: 5.43 for baseline and 1.64 for "deployed")

Occupant Delta-V (mph)	Vehicle Delta-V (mph)	Full Dummy Baseline AC HIC	Full Dummy Deployed AC HIC	Pole Test Actual and Estimated Baseline HPS HIC	Pole Test Actual and Estimated Average "Deployed" HPS HIC	Pole Test Actual & Estimated Sales Weighted "Deployed" HPS HIC
0	0	0	0	0	0	0
4.5	6	189	185	1,026	113	114
8.9	12	657	302	3,564	184	173
11.5	15	1226	390	6,655	238	240
12.3	16	1392	415	7,559	253	258
13.4	17	1638	468	8,888	285	281
13.8	18	1871	592	10,152	360	311
15.4	20	2690	602	14,596	367	317

The derived dummy HIC scores with the SID-H3 for the production HPS are plotted with corresponding vehicle delta-V's in Figure B-2. The best-fit line for the given data is shown as a polynomial equation in the figure.

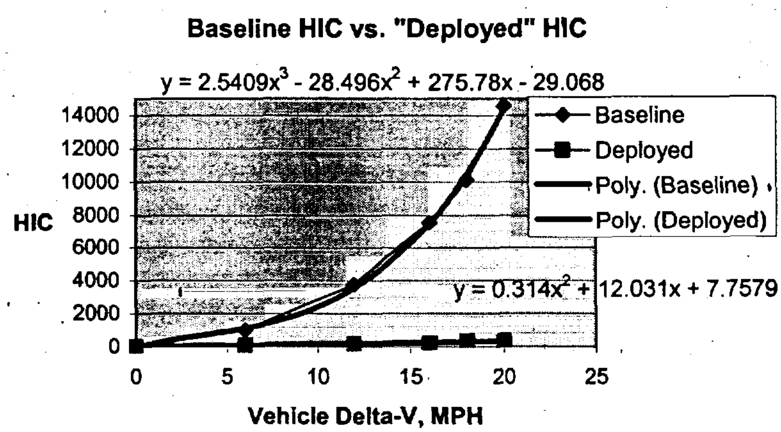


Figure B-2. Derived SID-H3 HIC Scores Plotted with Vehicle Delta-V (for pole sled crashes)

For delta-V's greater than 20 mph, HPS would deflate completely[62], as illustrated in Figure B-3

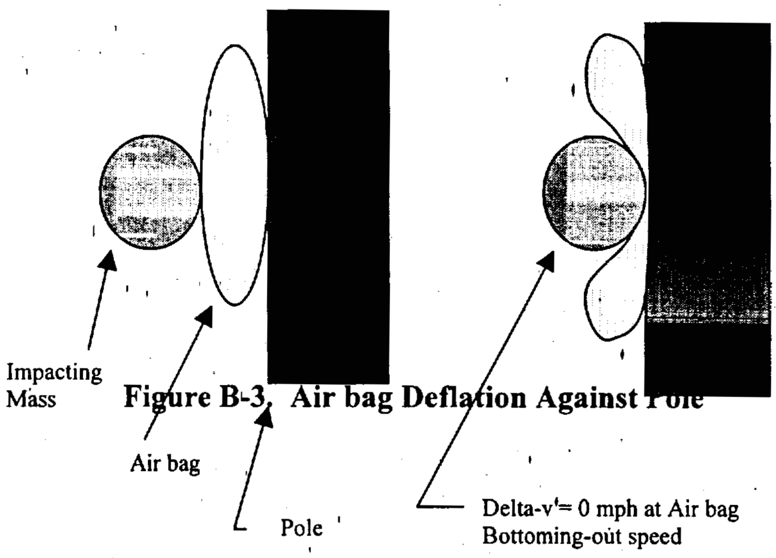


Figure B-3. Air bag Deflation Against Pole

As shown in Figure B-3, the head would experience a zero impact speed at the pole with a vehicle delta-V of 20 mph (i.e., at occupant delta-V of 15.4 mph). In other words, the air bag absorbs the entire kinetic energy (KE) associated with a mass (i.e., the head) traveling at 15.4 mph (assuming no energy loss, such as friction etc.). According to the conservation of energy theory, the relationship is expressed, as shown below:

$$\text{Kinetic Energy, KE} = \tfrac{1}{2}(M_{\text{head, effective}})(V^2_{\text{at 15.4 mph}})$$
$$= \tfrac{1}{2}(M_{\text{head, effective}})(15.4)^2$$
$$= \tfrac{1}{2}(M_{\text{head, effective}})(237.1)$$

For vehicle delta-V's higher than 20 mph, kinetic energy associated with the head impacts with a narrow object is expressed by the following equation:

$$\tfrac{1}{2}(M)(V^2_{\text{impact speed at pole}}) = \tfrac{1}{2}(M)(V^2_{\text{impact speed at air bag}}) - \tfrac{1}{2}(M)(237.1_{\text{at 15.4 mph}})_{\text{energy loss}}$$

[62] Based on an assumption that air bags bottom out at a vehicle delta-V of 20 mph.

For example, at a vehicle delta-V of 26.9 mph (i.e., at occupant delta-v of 20.72 mph), the head would impact the pole at an occupant delta-V of 13.86 mph, as shown below:

$$\tfrac{1}{2}(M)(V^2_{\text{impact speed at pole}}) = \tfrac{1}{2}(M)(20.72)^2 - \tfrac{1}{2}(M)((15.4)^2_{\text{energy loss}}$$

$$= \tfrac{1}{2}(M)(429.23) - \tfrac{1}{2}(M)(237.1)$$

$$= \tfrac{1}{2}(M)(13.86)^2$$

Thus, $V_{\text{at the pole}}$ = 13.86 mph (which is the occupant, not vehicle speed)

As shown in the example above, when a vehicle impacts with a pole at a vehicle delta-V of 27 mph, the head (of a test dummy) would impact with the air bag at 21 mph (i.e., 20.72 mph) and (subsequently) the pole at 14 mph (i.e., 13.86 mph). Regarding the HIC measurement, since the HIC formula/equation is based on peak acceleration, only the highest HIC score would be measured at a given impact speed. For example, at a vehicle delta-V of 27 mph, the head would experience a peak HIC score of 559 with the air bag (at an occupant delta-V of 20.7 mph). When the head impacts with the pole (after air bag bottoms out) at 14 mph, it would experience a peak HIC score of approximately 10,152 based on the baseline HIC profile at an occupant delta-V of 14 mph. Thus, a HIC score of 10,152 would be measured with the head in this example. The adjusted HIC scores and profiles are shown in Table B-4 and Figure B-3, respectively.

Table B-4
Estimated HIC Scores for Head Impacts with Pole (with SID-H3)

Vehicle Delta-V (mph)	Occupant Delta-V at Air bag (mph)	Occupant Delta-V at Pole (mph)	Baseline HIC at Given Delta-V (at Pole)		Deployed HIC measured at Air bag	HIC measured at Pole	HIC measured with Test Dummy (based on the occupant Delta-V)
			Speed	HIC			
1	N/A	0.77	0.77	221	N/A	221	221
2	N/A	1.54	1.54	429	N/A	429	429
4	N/A	3.08	3.08	781	N/A	781	781
6	N/A	4.62	4.62	1,149	N/A	1,149	1,149
8	N/A	6.15	6.15	1,654	N/A	1,654	1,654
10	N/A	7.69	7.69	2,420	N/A	2,420	2,420
15	11.53	0	11.53	6,272	259	0	259
16	12.31	0	12.31	7,496	281	0	281
18	13.85	0	13.85	10,521	326	0	326
20	15.40	0	15.40	14,415	374	0	374
21	16.15	4.88 (6.34#)	16.15	16,727	374	1,221	1,221
22	16.92	7.02 (9.12#)	16.92	19,301	374	2,043	2,043
24	18.46	10.18 (13.23#)	18.46	25,301	374	4,516	4,516
26	20.00	12.76 (16.59#)	20.00	32,537	374	8,305	8,305
28	21.54	15.06 (19.58#)	21.54	41,130	374	13,519	13,519
30	23.08	17.19 (22.35#)	23.08	51,202			
32	24.62	19.21 (24.98#)	24.62	62,876			
34	26.15	21.13 (27.47#)	26.15				

* The term "Baseline" means "without air bag deployment."
\# Vehicle delta-V.

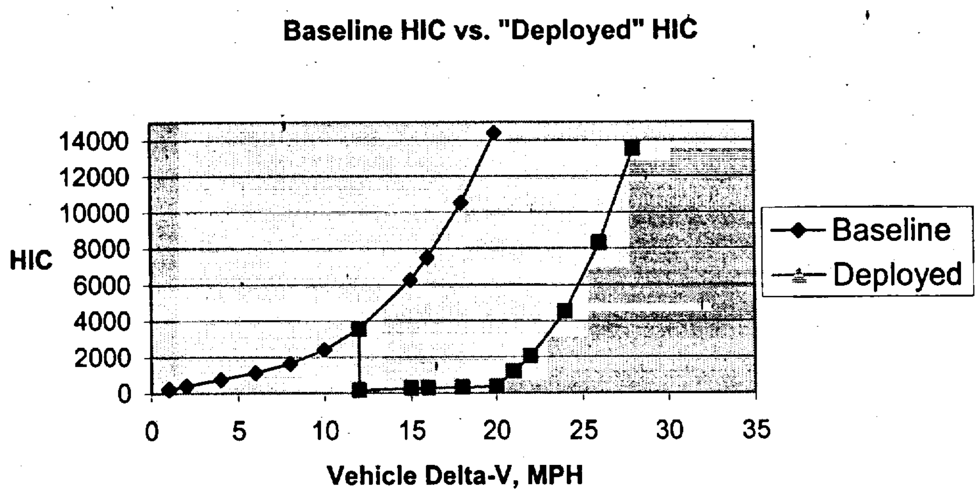


Figure B-4. Baseline and "deployed" HIC Profiles for Production HPS in Side Pole Impact

The "deployed" HIC profile in Figure B-4 shows that HIC level would increase rapidly when air bag collapses in pole impacts. For example, according to the profile, a HIC score of 2,043 would be reached at a vehicle delta-V of 22 mph.

2.1.2 Side Crashes Involving Occupant Head Impacts with Vehicle Interior Components:

Head injuries: In the Preliminary Regulatory Evaluation of FMVSS No. 201, (April 1997), the ITS HPS system was evaluated by a series of (sled) pole tests [63] with a Eurosid instrumented test dummy, with the results shown in Table B-5.

Table B-5
ITS HPS Sled Pole Tests Results
(Performed with the EuroSid instrumented dummy)

Speed (Km/hr)	Speed (mph)	Occupant Delta-V (mph)	Occupant Delta-V (m/s)	Head Contact	Base HIC (w/o ITS)	ITS HIC
27	16.78	12.84	5.7	B-pillar	700	270
51	31.69	24.24	10.8	B-pillar	1900	560
27	16.78	12.84	5.7	Window closed	80	250
51	31.69	24.24	10.8	Window open	190	230
30	18.64	14.26	6.4	Pole	2,495	331

The results indicate that the ITS HPS would reduce head injuries that occur at the B-pillar and at the front side door contact points in side crashes. Since crash data were not available at the front door or other interior components, the B-pillar HIC results were used as a proxy measure for those head contact points. (In other words, we assumed that the front door and other interior components produce the same HIC score. In addition, although the SID-H3 would respond differently, due to limited data, it was assumed that the SID-H3 produces the same HIC response as the Eurosid in the same crash environment under consideration.) For the baseline HIC scores,

[63] See NHTSA Docket No. 92-28-04-013 for additional discussion.

the ITS "full" dummy HIC scores were translated into Free Motion Head-form (FMH) HIC scores using the derived formula:

$$\text{FMH HIC} = (\text{Full Dummy HIC} - 166.4)/0.75446$$

Based on the formula, the FMH HIC scores were derived, as shown in Table B-6.

Table B-6
Baseline FMH HIC Scores Converted from (Full) Dummy HIC

Vehicle Delta-V (mph)	Occupant Delta-V (mph)	Head Contact	Baseline Dummy HIC (i.e., w/o ITS)	Baseline FMH HIC (converted)
16.78	12.84	B-pillar	700	707
31.69	24.24	B-pillar	1,900	2,298

The baseline pole HIC scores for the production HPS at a vehicle delta-V of 16 mph and 18 mph were derived from the baseline HIC's at a vehicle delta-V of 16.78 mph (an occupant delta-V of 12.84 mph). According to the structural vibration theory, the acceleration response of a simple, linear elastic system is a function of its <u>initial velocity</u> if the system's initial displacement equals zero. This system model simulates the head form-to-pillar impacts very well[64]. Based on the theory, FMH HIC scores at a vehicle delta-V of 16 mph and 18 mph were derived, as shown in Table B-7.

Table B-7
FMH HIC Scores at 16 mph and 18 mph, Head Impacts with
Vehicle Interior Components, based on HIC score at occupant delta-V of 12.84 mph)

Speed (mph)	Occupant Delta-V (mph)	Conversion Factor derived from the theory	FMH HIC, Estimated with Conversion Factor	FMH HIC, Actual
16	12.24	0.887	627	No data
16.78	12.84	1	707	707
18	13.77	1.191	842	No data

[64] Additional discussion is found in "Head Impact Energy Absorbing Dynamic Systems (HEADS), Amendments to FMVSS No. 201, Upper Interior Head Protection," page B-26.

Accordingly FMH HIC scores were derived based on HIC scores at 16 mph and 18 mph, and the derived FMH HIC scores were converted into full dummy HIC scores, as shown in Table B-8.

Table B-8
Baseline HIC for Head Impacts with B-pillar, with 50th Percentile Test Dummy

Vehicle Delta-V (mph)	Occupant Delta-V (mph)	FMH HIC, Estimated	Dummy Baseline HIC, Estimated	Dummy Baseline HIC, Actual
2	1.53	4	169	No data
4	3.07	20	181	No data
5	3.85	35	193	No data
6	4.62	54	207	No data
7	5.38	98	240	No data
8	6.15	111	250	No data
9	6.92	151	280	No data
10	7.69	194	313	No data
12	9.23	306	397	No data
12.80	9.84	359	437	No data
13.2	10.18	396	465	No data
14	10.77	450	506	No data
15	11.54	534	569	No data
16	12.24	627	639	No data
16.78	12.84	707	700	700
18	13.77	842	802	No data
19	14.62	965	894	No data
20	15.30	1096	*	No data
25	19.13	1,271[1]	*	No data
31.69	24.24	2,298	1900	1900

1. Based on HIC score of 1900 at a vehicle delta-V of 31.69 mph. * not estimated.

Since the derivation based on the HIC score of 700 (at occupant delta-V of 12.84 mph) would produce a large error for delta-V's close to 31.69 mph, the HIC score of 1900 (at a delta-V of 31.69mph) was used as the base for estimating HIC scores for delta-V's close to 31.69 mph[65]. The adjusted baseline HIC scores are shown in Table B-9.

[65] Note that the estimated baseline HIC scores in Table B-8 show that the HIC level at a vehicle delta-V of 16 mph would be very close to a HIC level at 16.78 mph, as expected. However, the estimation based on the HIC score at an occupant delta-V of 12.84 mph overestimates the HIC level at a vehicle delta-V of 31.69 mph (a 46% overestimation.

Table B-9
Full Dummy HIC for Impacts with B-pillar

Vehicle Delta-V (mph)	Occupant Delta-V (mph)	Full Dummy baseline HIC, Estimated & Actual	Full Dummy HIC, Actual
15	11.5	569	No data
16	12.3	639	No data
16.78	12.8	700	700
18	13.8	802	No data
19	14.6	894	No data
20	15.3	919*	No data
22	16.9	1,071*	No data
24	18.5	1,238*	No data
25	19.13	1,327*	No data
26	20.0	1,420*	No data
28	21.5	1,619*	No data
29	22.3	1,725*	No data
31.69	24.2	1,900	1900
32	24.5	1,945	No data
39	29.9	3,084	No data

* Based on $HIC(DV) = 1.9892(Dv)^2 - 8.0128(Dv) + 284.13$

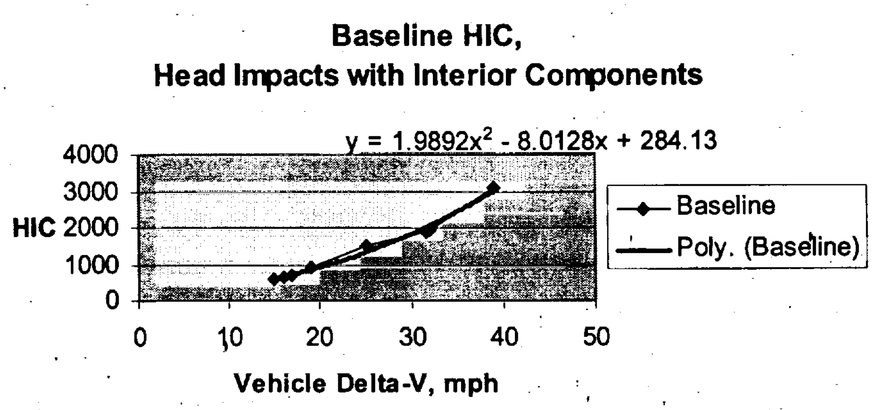


Figure B-5. Baseline HIC for Head Impacts with Vehicle Interior Components

For the "deployed" HPS HIC scores for delta-V's less than or equal to 20 mph, due to limited data, the "deployed" HIC profile developed previously for the impacts with narrow objects case was considered as a proxy measure for HIC. For delta-V's higher than 20 mph (i.e., higher than the assumed air bag bottoming-out speed), the "deployed" HIC profile would be similar to the baseline HIC profile (resulting from the head-to-vehicle interior components impacts) for a given delta-V at vehicle interior vehicle interior components since the air bag would be in its deflated stage. As discussed previously, head impact speed at the vehicle interior components (after air bag deflation) was derived based on the initial vehicle delta-V's and the kinetic energy associated with the head. The derived delta-V's and the associated HIC scores are shown in Table B-10.

Table B-10
Estimated HIC Scores for Head Impacts with Interior Components

Vehicle Delta-V (mph)	Occupant Delta-V (mph) at Air bag	Occupant Delta-V (mph) at Vehicle interior components	Baseline HIC at Given Delta-V (at Vehicle interior components)		Deployed HIC measured at Air bag	HIC measured at Vehicle interior components	HIC measured with Test Dummy
			Impact Speed	HIC			
1	N/A	0.77	0.77	278	N/A	278	278
2	N/A	1.54	1.54	276	N/A	276	276
4	N/A	3.08	3.08	283	N/A	283	283
6	N/A	4.62	4.62	308	N/A	308	308
8	N/A	6.15	6.15	347	N/A	347	347
10	N/A	7.69	7.69	403	N/A	403	403
14	N/A	10.77	10.77	562	N/A	562	562
15	11.53	0	11.53	612	259	0	259
16	12.31	0	12.31	665	281	0	281
18	13.85	0	13.85	784	326	0	326
20	15.40	0	15.40	920	374	0	374
21	16.154	4.88 (6.34)[3]	16.15	993	374	313	374
22	16.923	7.016 (9.12)	16.92	1,071	374	377	377
24	18.46	10.18 (13.23)	18.46	1,238	374	526	526
26	20.00	12.8 (16.59)	20.00	1,420	374	699	699
28	21.54	15.06 (19.58)	21.54	1,619	374	890	890
30	23.08	17.19 (22.35)	23.08	1,834	374	1,099	1,099
32	24.62	19.21 (24.98)	24.62	2,065	374	1,325	1,325
34	26.15	21.13 (27.47)	26.15	2,311	374	1,565	1,565

1. Baseline HIC scores are based on the structural vibration theory and the HIC scores at 16.78 mph and 31.69 mph, respectively. See previous tables.
2. The derived deployed HPS HIC profile was used as a proxy measurement (rather than the ITS deployed HIC) because the ITS HPS would not represent overall performance of production HPS.
3. Corresponding vehicle delta-V's are in parentheses.

Regarding performance of the production HPS and the ITS HPS, note that a HIC score of 270 was measured with the ITS at 16.78 mph whereas a HIC score of 298 was estimated with the production HPS at 16.78 mph. The scores show that the "deployed" HPS HIC profile is a good proxy for the ITS at this vehicle delta-V. However, the estimated "deployed" HPS HIC of 1,325 at a vehicle delta-V of 32 mph is much higher than the "deployed" HIC of 560 measured with the ITS at 31.69 mph. It is suspected that the ITS HPS has a higher bottoming-out speed compared to the assumed 20 mph for the production HPS. If the bottoming out speed of the production HPS were 26 mph the estimated "deployed" production HPS HIC score is very close to the ITS HIC score measured at 31.69 mph, as shown below:

$$\tfrac{1}{2}(M)V^2_{\text{at a vehicle delta-V of 30 31.69 mph}} = \tfrac{1}{2}(M)(20)^2_{\text{at a 26 mph}}) + \tfrac{1}{2}(M)(V^2_{\text{, impact speed at the vehicle interior components}})$$

$$\tfrac{1}{2}(M)(V^2_{\text{, impact speed at the vehicle interior components}}) = \tfrac{1}{2}(M)(24.37)^2 - \tfrac{1}{2}(M)(20)^2$$

$$= \tfrac{1}{2}(M)(594.38) - \tfrac{1}{2}(M)(400)$$

$$= \tfrac{1}{2}(M)(13.9)^2_{\text{occupant delta-V}}$$

According to the derived "deployed" HPS HIC profile, the production HPS would produce a "deployed" HIC of approximately 557 at a vehicle delta-V of 31.69 mph if the air bag bottoms out at a vehicle delta-V of 26 mph. The production HPS HIC score (i.e., 557) is very close to the measured ITS HIC of 560 at a vehicle delta-V of 31.69 mph. If the operating air bag internal pressure of the ITS is similar to the air bag operating pressure of the production HPS system, in order to have a higher bottoming out speed, the thickness of the "deployed" ITS must be greater. For example, according to the HIC scores, the ITS would bottom out at a vehicle delta-V of 26 mph if its thickness is 1.7 times of the production HPS, as shown below:

Work, $\mathcal{W} = \int F \bullet R = F \times L_{\text{Displacement}}$ (assuming linear displacement with a constant force.)

Kinetic Energy, $KE = \frac{1}{2} M(V_{1,\text{ air bag bottoming out speed}})^2$

$\Delta KE = \mathcal{W}$ (assuming no energy loss.)

$\frac{1}{2} MV_1^2 = F \times L_{\text{Displacement}}$

As for the air bag bottoming –out speeds,

$V_2/V_1 = (26)/(20)$

$= 1.3$

$V_2 = (1.3)V_1$

$= [(1.7)^{1/2}]V_1$

Then, $\frac{1}{2} M(V_{2,\text{ air bag bottoming out speed}})^2 = (1.7)[\frac{1}{2} M(V_{1,\text{ air bag bottoming out speed}})^2]$

$= (1.7)(F \times L_{\text{Displacement}})$

In other words, when thickness of the production HPS air bag increases by 1.7 times, it would increase the bottoming out speed by 30%.

The derived baseline and "deployed" HIC scores are summarized in Table B-11.

Table B-11
Estimated HIC Scores for Head Impacts with Vehicle Interior Components

Vehicle Delta-V (mph)	Occupant Delta-V (mph)	Baseline HIC (Estimated)	"Deployed" HPS HIC (Adjusted, Estimated)
15	11.54	612	259
16	12.18	665	281
18	13.71	784	326
20	15.23	920	374
22	16.92	1,071	377
24	18.46	1,238	526
26	20.00	1,420	699
28	21,54	1,619	890
30	23.08	1,834	1,099
32	24.49	2,065	1,325

The actual and estimated baseline and "deployed" HPS HIC scores for the head impacts with vehicle interior component case are plotted in Figure B-6.

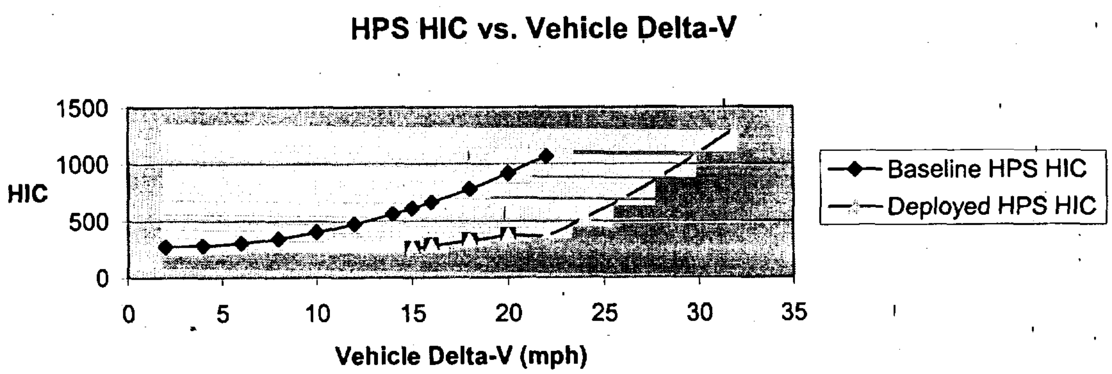


Figure B-6. Baseline and deployed HIC's resulting from head impacts with vehicle interior components

As expected, at a given delta-V, the baseline HIC profile shows that HIC scores resulting from impacts with vehicle interior components would be lower than HIC scores resulting from impacts with a pole in side crashes. For vehicle delta-V's greater than 20 mph, the derived "deployed" HPS HIC scores indicate that HPS would enhance effectiveness of vehicle interior vehicle interior components by absorbing initial kinetic/impact energy.

2.1.3. Non-Rollover Side Crashes Involving Complete Occupant Ejection: When an occupant is ejected from a vehicle through a side window during a non-rollover side crash, the head and other body parts would be in contact with roadside objects and hardware or the front surface of the striking vehicle. (Head impacts with striking vehicles are discussed separately in the following section.) Thus, severe head injuries resulting from these impacts would be comparable to head injuries resulting from impacts with non-deforming surfaces, such as tree or pole. On the other hand, the head of the occupant may be in contact with compliant external objects or other occupants in the vehicle. HPS would be effective in reducing injuries at delta-V's far greater than its bottoming-out speed. For example, at a vehicle delta-V of 31.69 mph, the Inflatable Tubular System (ITS) HPS would prevent occupants from ejection with a low probability of head injury (i.e., HIC of 230 with window open.) Note that since combo HPS with its narrow air bag size may not properly retain occupants, only air curtain HPS and the ITS HPS were considered for the analysis. According to the vehicle sales, approximately 52% of HPS are either air curtain (AC) or the ITS type. Thus, the benefits were adjusted by considering only 52% of the target population.

Head injuries: For the baseline HIC, all head injuries resulting from non-rollover side window ejection cases were treated as a "narrow object" impact case in terms of HIC level. For example, if the head of a test dummy receives HIC of 10,151 during a pole crash at a vehicle delta-V of 18 mph, under our assumption, the head would receive the same HIC level of 10,151 if the dummy had been ejected from a vehicle (in a side crash) at the same vehicle delta-V. Since the fatality rate is higher for ejected occupants than non-ejected, this assumption is warranted. Accordingly, the baseline HIC profile developed for the head impacts with narrow object case was used as a proxy for the complete occupant ejection case. (Note that the approach implies that all complete occupant ejection cases are resulted from vehicle-to-pole non-rollover side crashes. However, occupant ejections do occur in vehicle-to-vehicle side crashes and the occupant ejection velocity would be lower in vehicle-to-vehicle crashes compared to vehicle-to-pole crashes at a given vehicle delta-V. Although a low ejection speed would result in a low injury probability, HIC scores resulting from ejection would be much higher than the threshold head injury level (of 1,000) regardless of the causation of ejection.) For the "deployed" HIC profile, both "window open" and "window closed" cases were considered. According to the ITS HPS sled test results, window/glazing marginally increases HIC level, as shown in Table B-12.

Table B-12
"Deployed" HIC Levels with Side Window Open and with Side Window Closed
(ITS Sled Pole Test)

Vehicle Delta-V (km/h)	**Vehicle Delta-V (mph)**	**Occupant Delta-V (mph)**	**Head Contact**	**ITS HIC**
27	16.78	12.84	Window Closed	250
27	16.78	12.84	Window Open	230

The results in Table B-12 show that a higher HIC score (i.e., 250) was measured with window closed. (Further discussion is found in Docket No. 92-28-04-013.) According to the ITS test report, the head of the dummy swings out through the broken window without the ITS, usually without impacting the car frame. With the ITS employed, the ITS prevented the dummy head from swinging out of the broken window. 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[66]. The ITS HIC results in Table B-12 show that increase in HIC level due to glazing/window would be insignificant for a given test condition. The HIC scores measured with the ITS HPS were further compared with HIC scores based on the "deployed" HIC profile derived for the impacts with narrow objects case, as shown in Table B-13.

Table B-13
Estimated "deployed" HIC Scores for Impact with Side Window Closed & Open

Vehicle Delta-V (mph)	"Deployed" Production HPS HIC (Pole Test)[1]	ITS HIC (Pole Test)[2]	
	Window open	Window open	Window closed
16.78	298	230	250

1. Based on vehicle-to-pole impact "deployed" HIC profile.
2. Based on the ITS sled pole test results.

Since the ITS and an curtain HPS are different in terms of HIC responses, the ITS HIC score measured at a vehicle delta-V of 16.78 mph was further adjusted. According to the derived relative performance, the Production HPS would produce 5.6 % higher HIC score at a given delta-V compared to the production HPS, as shown in Table B-14.

[66] The report concludes that the advance glazing tested did not significantly increase the head injury potential over standard tempered glass side windows.

Table B-14
Estimated "deployed" HIC Scores for Impact with Side Window Closed & Open

Vehicle Delta-V (mph)	**"Deployed" Production HPS HIC (Pole Test)**	**ITS HIC (Pole Test)**		**ITS HIC adjusted with Production HPS[1] (i.e., Production HIC Equivalent)**	
	Window open	**Window open**	**Window closed**	**Window open**	**Window closed**
16.78	298	230	250	243	264

1. ITS HIC = 340 whereas Production HPS HIC = 360 at 18 mph with SID H-3. (360 –340)/360 = 0.056 (5.6%)

The production "equivalent" ITS HIC scores (i.e., HIC of 243 and 264 in Table B-14) show that the effects of glazing/window are insignificant in terms of HIC level and that the use of the "deployed" HIC scores derived from the vehicle-to-pole test results would be a reasonable proxy for HIC scores in the occupant ejection case. The derived baseline and "deployed" production HPS HIC scores for the head of an ejected occupant impacts with rigid external objects are shown in Figure B-7.

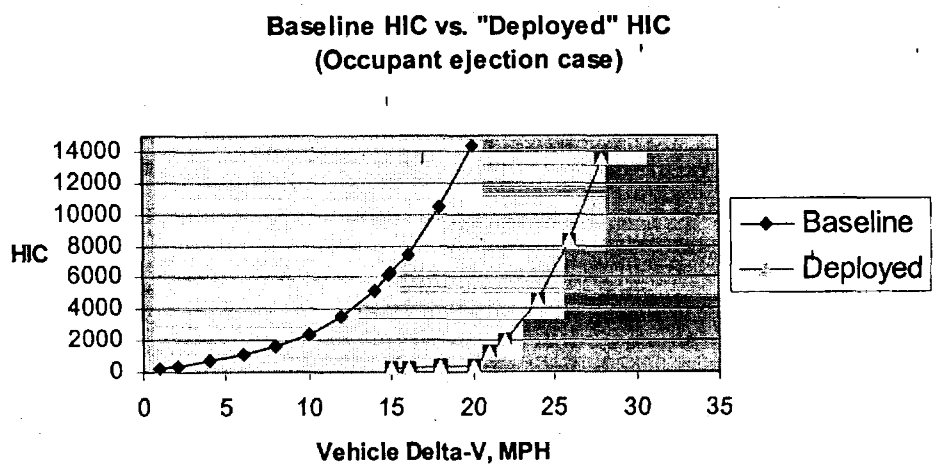


Figure B-7. Derived HIC Scores for Occupant Ejection Case with SID-H3

2.1.4. Side Crashes Involving Occupant Head Impacts with Front of Striking Vehicle: In vehicle-to-vehicle side crashes, deformation of the striking vehicle absorbs part of impact energy resulting in a lower dummy speed with respect to structure of the struck vehicle when compared to vehicle-to-pole/tree crashes. Although the deformation would reduce the HIC scores (that would be measured in vehicle-to-pole crashes at a given delta-V), the reduction would be insignificant in terms of injury probability. For example, if the deformation reduces the pole HIC level measured at a vehicle delta-V of 12 mph by 50%, it would result in a HIC score of 3,136 at 12 mph. According to the HIC injury risk curves, this HIC score would result in 99.6% probability of fatality[67]. Therefore, when the head of an occupant impacts with the striking vehicle in side crashes, head injury (AIS) levels resulting from the impact would be comparable to injury levels resulting from impacts with non-deformable surfaces, such as a pole or tree.

Head injuries: As mentioned, the baseline HIC profile developed for the impacts with narrow objects case was used as a proxy for the baseline profile for the head impacts with the striking vehicle's exterior surface case; for the "deployed" HIC profiles, the "deployed" HIC profile developed for the impacts with vehicle interior occupants case was used as a proxy, as shown in Table B-15.

[67] As for chest and pelvic injuries, since the occupant is retained in the vehicle during the impact, the injury levels would be comparable to injury levels resulting from impacts with vehicle interior components in vehicle-to-vehicle crashes.

Table B-15
Estimated Baseline and "Deployed" HIC for Impacts with Striking Vehicle Case

Vehicle Delta-V	Baseline HIC[1]	"Deployed" HIC[2]
15 mph	6,272	259
16 mph	7,496	281
18 mph	10,152	326
20 mph	14,415	374
22 mph	19,301	377
24 mph	25,301	526

1. The HIC profile derived for the narrow object impact case.
2. The "deployed" HIC profile derived for the occupant ejection case in vehicle-to-vehicle crashes.

2.1.5. Side Crashes Involving No Head Contact (excluding complete occupant ejection): The case under consideration includes side crashes where a high ride vehicle (such as an SUV) is struck by a low ride vehicle (such as passenger car) in non-rollover, non-ejection, no head impacts with interior components side crashes[68]. (Note that although extremity injuries, such as hand and shoulder injuries are common in partial occupant ejection crashes. This analysis does not include benefits, if any, for such injuries.)

Head injuries: For head injuries, when the head of an occupant impacts the side window (regardless of whether it is closed or not), the resulting HIC score would be very low even at high impact speeds, as shown in Table B-16.

Table B-16
ITS HIC scores at a vehicle delta-V of 16.78 mph

ITS	Head Contact	HIC	Probability of MAIS 3+
No	Closed Window (broken)	80	0.4%
Yes	ITS with closed window	250	3%
No	Open Window	190	2%
Yes	ITS with open window	230	3%

[68] See previous discussion on open & closed windows in side crashes.

Since difference in injury probability between the baseline and the "deployed" HPS would be relatively small at a given delta-V, regardless of air bag deployment and window opening, neither potential benefits nor dis-benefits were considered for the analysis.

2.2 Impact of Pole Test with ES-2 Test Dummy

2.2.1 Side Crashes Involving Occupant Head Impacts with Narrow Objects:

Head Injuries: Similar to the methodology used for the SID-H3, the pendulum test results and the pole test results at 18 mph were used to derive HIC scores that would be measured with the ES-2 50^{th} percentile male test dummy in the FMVSS No. 201 optional pole test, as shown in Table B-17.

Table B-17
Pendulum and Average HIC Resulting from ES-2 Sled Pole Tests

Occupant Delta-V (mph)	Vehicle Delta-V (mph)	Dummy Baseline AC HIC	Dummy Deployed AC HIC	Pole Test Avg. Baseline HPS HIC	Pole Test Avg. "Deployed" HPS HIC
4.5	5.9	189	185	No data	No data
9.2	12.0	657	302	No data	No data
11.5	15.0	1226	390	No data	No data
12.3	16.0	1392	415	No data	No data
13.4	17.4	1638	468	No data	No data
13.8	18.0	1871	592	6,866	230
15.4	20.0	2690	602	14,242	502
15.7	20.4	2807	627	No data	No data

By comparing HIC scores at a vehicle delta-V of 18 mph, it was determined that the baseline HIC scores resulting from the sled pole test are approximately 4.48 times higher on average than the baseline HIC scores resulting from the pendulum test. In addition, the "deployed" HIC scores resulting from the sled pole test are approximately 2.57 times <u>lower</u> than the "deployed"

AC HIC resulting from the pendulum testing. These factors were applied to the dummy HIC scores to derive pole HPS HIC scores, as shown in Table B-18.

Table B-18
Pendulum and Average HIC Resulting from Pole Tests

Occupant Delta-V (mph)	Vehicle Delta-V (mph)	Dummy Baseline AC HIC	Dummy Deployed AC HIC	Pole Test Estimated Baseline HPS HIC	Pole Test Estimated Deployed HPS HIC
4.5	5.9	189	185	693	72
9.2	12.0	657	302	2,411	118
11.5	15.0	1226	390	4,499	152
12.3	16.0	1392	415	5,109	161
13.4	17.0	1638	468	6,011	182
13.8	18.0	1871	592	6,866	230
15.4	20.0	2690	602	14,242	502

The derived HPS pole HIC scores with the ES-2 are plotted with corresponding vehicle delta-V's in Figure B-8.

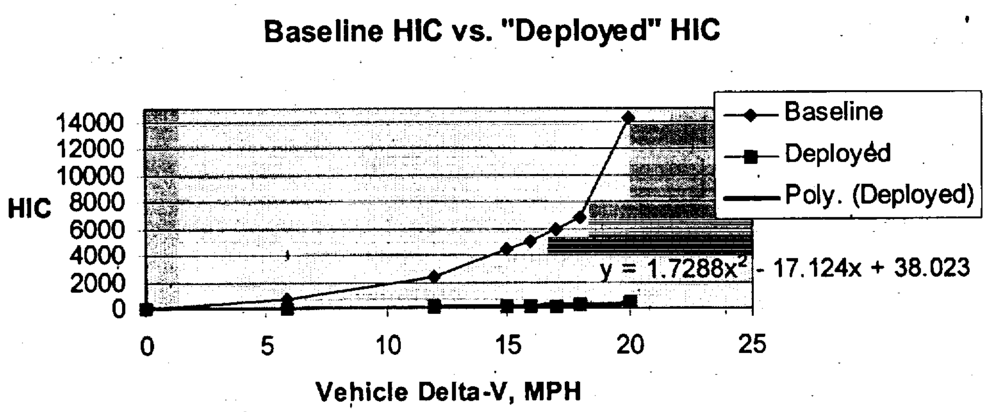


Figure B-8. Derived HPS HIC scores plotted with vehicle delta-V with ES-2

For delta-V's greater than 20 mph, as assumed, HPS would be in its deflated stage. As discussed, kinetic energy associated with a head impacts with a narrow object is expressed by the following equation:

$$\frac{1}{2}(M)(V_{\text{impact speed at pole}})^2 = \frac{1}{2}(M)(V_{\text{impact speed at air bag}})^2 - \frac{1}{2}(M)(15.4\text{ mph})^2_{\text{energy absorbed by air bag}}$$

The adjusted HIC scores and profiles are shown in Table B-19 and Figure B-9, respectively.

Table B-19
Estimated HIC Scores for Head Impacts with Pole (with ES-2)

Vehicle Delta-V (mph)	Occupant Delta-V at Air bag (mph)	Occupant Delta-V at Pole (mph)	Baseline HIC at Given Delta-V (at Pole)		Deployed HIC measured at Air bag	HIC measured at Pole	HIC measured with Test Dummy (based on the occupant Delta-V)
			Speed	HIC			
1	N/A	0.77	0.77	115.5	N/A	115.5	115.5
2	N/A	1.54	1.54	231	N/A	231	231
4	N/A	3.08	3.08	462	N/A	462	462
6	N/A	4.62	4.62	693	N/A	693	693
8	N/A	6,15	6.15	1,265	N/A	1,265	1,265
10	N/A	7.69	7.69	1,838	N/A	1,838	1,838
12	N/A	9.23	9.23	2,411	N/A	2,411	2,411
14	N/A	10.77	10.77	3,760	N/A	3,760	3,760
15	11.53	0	11.53	4,499	152	0	152
16	12.31	0	12.31	5,109	161	0	161
18	13.85	0	13.85	6,866*	230	0	230
20	15.40	0	15.40	14,242*	502	0	502
21	16.15	4.88 (6.34#)	16.15	17,930	502	790	790
22	16.92	7.016 (9.12#)	16.92	21,618	502	1,586	1,586
24	18.46	10.18 (13.234#)	18.46	28,994	502	3,243	3,243

1. Actual measurement.
#. Vehicle delta-V

(Note: Equation used for the estimation at given delta-V range. This table should be pulled out from the final document)

(Vehicle) Delta-V range (mph)	Baseline HIC Estimate	"Deployed" HIC Estimate
0 - 6	HIC = 115.5 Dv	HIC = 11.8 Dv
6 - 12	HIC = 286.3 Dv – 1025	HIC = 7.667 Dv + 25
12 - 16	HIC = 674.5 Dv – 5683	HIC = 10.75 Dv –12
16 - 18	HIC = 878.5 Dv – 5347	HIC = 34.5 Dv – 392
18 – 20	HIC = 3688 Dv – 59518	HIC = 85 Dv –1301
20 - 22	HIC = 3688 Dv – 59518	

(Where Dv = Vehicle Delta-V).

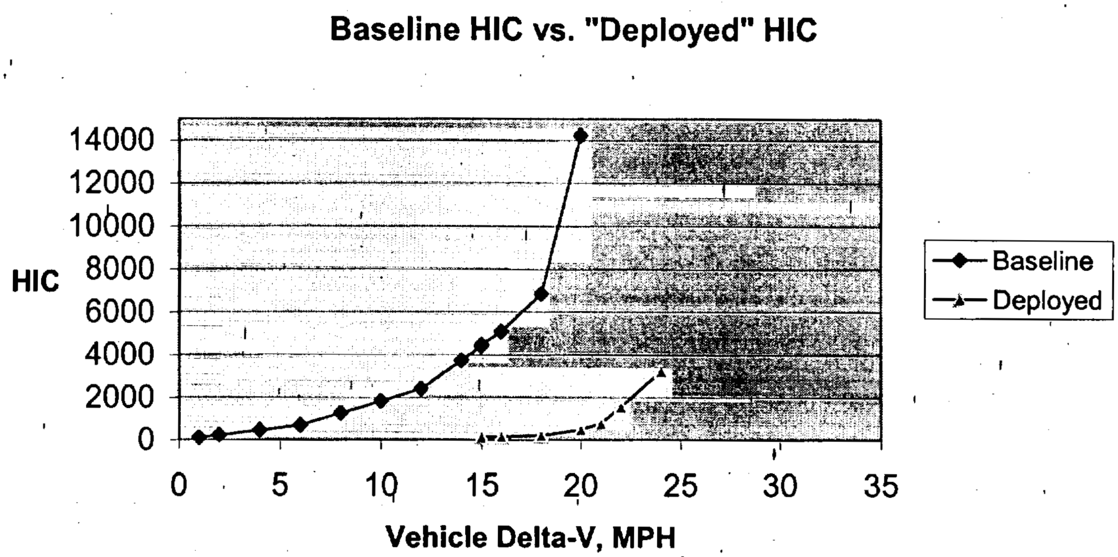


Figure B-9. Estimated Baseline and "deployed" HIC Profiles with ES-2

Similar to the "deployed" SID-H3 HIC profile, the "deployed" (ES-2) HIC profile in Figure B-9 shows that HIC level increases rapidly when the air bag is deflated in narrow (rigid) object crashes.

2.2.2 <u>Side Crashes Involving Occupant Head Impacts with Vehicle Interior Components</u>:

<u>Head Injuries</u>: For the analysis, the HIC scores resulting from the previously discussed ITS (HPS) sled test were examined. It was assumed that the ES-2 produces the same response (with respect to HIC) as Eurosid for the head impact with vehicle interior components. Under this assumption, the ES-2 would produce the same HIC response at a given delta-V as the SID-H3, and consequently produces the same benefits for head injuries as the SID-H3

2.2.3 <u>Non-Rollover Side Crashes Involving Complete Occupant Ejection</u>:

<u>Head Injuries</u>: For the baseline HIC, similar to the methodology used for the SID-H3 case, all head injuries resulting from non-rollover side window ejection cases were considered as a

"narrow object" impact case in terms of HIC level. Thus, the baseline HIC profile developed for the impacts with narrow objects case was used as a proxy for the baseline HIC profile for the occupant ejection case. For the "deployed" HIC, the profile deployed for the impacts with vehicle interior components case was used as a proxy (i.e., referred as "vehicle-to-vehicle crashes).

Table B-20
Estimated Baseline and "Deployed" HIC Scores for Non-Rollover
Side Crashes Involving Complete Occupant Ejection

Vehicle Delta-V (mph)	Baseline HIC[1]	"Deployed" HIC
14	3,760	N/A[2]
15	4,499	259
16	5,109	281
18	6,866	326
20	14,242	374
22	21,618	377

1. From the previously derived HIC profile for impacts with a narrow object/pole case.
2. Below the air bag deployment speed of 12 mph.

2.2.4 Side Crashes Involving Occupant Head Impacts with Front of Striking Vehicle:

Head Injuries: For the baseline HIC, all head injuries resulting from non-rollover side window ejection cases were treated as a "narrow object" impact case in terms of HIC level. Thus, the baseline HIC profile developed for the impacts with narrow objects case was used as a proxy for the head impacts with the front of the striking vehicle case. For the "deployed" HIC, the profile deployed for the impacts with vehicle interior components case was used as a proxy. The baseline and deployed HIC scores are shown in Table B-21.

Table B-21
Estimated Baseline and "Deployed" HIC Scores for
Non-Rollover Side Crashes Involving Complete Occupant Ejection

Vehicle Delta-V (mph)	Baseline HIC	"Deployed" HIC
15 –16	5,109	281
17 – 18	6,866	326
19 – 20	14,242	374
21 – 22	21,618	377
23 – 24	28,994	526

1.2.5 Side Crashes Involving No Head Contact:

Head Injuries: As discussed in the analysis of the ITS in high speed sled tests, HPS would not provide any significant benefits when the head does not impact with vehicle interior components or other exterior objects in crashes (referred as "No-head contact case"). Thus, similar to the approach used for the same case with the SID-H3, it was assumed that HPS does not provide any benefits when the head does not impact with external objects or interior components in side crashes.

2.3 Impact of Pole Test with SID-IIs Test Dummy

2.3.1 Side Crashes Involving Occupant Head Impacts with Narrow Objects:

Head Injuries: Similar to the methodology used for the SID-H3, the pendulum test results were used to derive HIC scores that would be measured with the SID-IIs (5th percentile test dummy). The dummy HIC scores were adjusted to reflect effects of real world crashes, as shown in Table B-22.

Table B-22
HIC Scores Resulting from Pendulum Test and **SID-IIs Sled** Pole Tests

Occupant Delta-V (mph)	Vehicle Delta-V (mph)	Dummy Baseline IC HIC	Dummy Deployed AC HIC	Pole Test Avg. Baseline HAB HIC	Pole Test Avg. Deployed HAB HIC
4.5	5.9	189	185	No data	No data
9.2	12.0	657	302	No data	No data
11.5	15.0	1226	390	No data	No data
12.3	16.0	1392	415	No data	No data
13.4	17.4	1638	468	No data	No data
13.8	18.0	1826	469	No data	No data
15.4	20.0	2690	602	11,534*	512
15.7	20.4	2807	627	No data	No data

* ½ (8,706 + 14,362) = 11,534

By comparing HIC scores at a vehicle delta-V of 20 mph, it was determined that the baseline HIC values resulting from the sled pole tests are approximately 4.29 times higher (average) than the baseline dummy HIC scores (derived from the pendulum tests). In addition, the "deployed" HIC scores resulting from the sled pole tests are approximately 1.18 times lower than the "deployed" AC dummy HIC (derived from the pendulum tests). These factors were applied to each vehicle delta-V, as shown in Table B-23.

Table B-23
Derived Baseline and Deployed HIC scores for Pole Impact (with SID-IIs)

Occupant Delta-V (mph)	Vehicle Delta-V (mph)	Dummy Baseline AC HIC	Dummy Deployed AC HIC	Pole Test Estimated Baseline HPS HIC	Pole Test Estimated Deployed HPS HIC
4.5	5.9	189	185	811	157
9.2	12.0	657	302	2,819	256
11.5	15.0	1226	390	5,260	331
12.3	16.0	1392	415	5,972	352
13.4	17.0	1638	468	7,027	397
13.8	18.0	1871	592	8,027	502
15.4	20.0	2690	602	11,533	512
15.7	20.4	2807	627	12,042	531

The derived HPS HIC scores with the SID-IIs for the production HPS are plotted with corresponding vehicle delta-V's in Figure B-10.

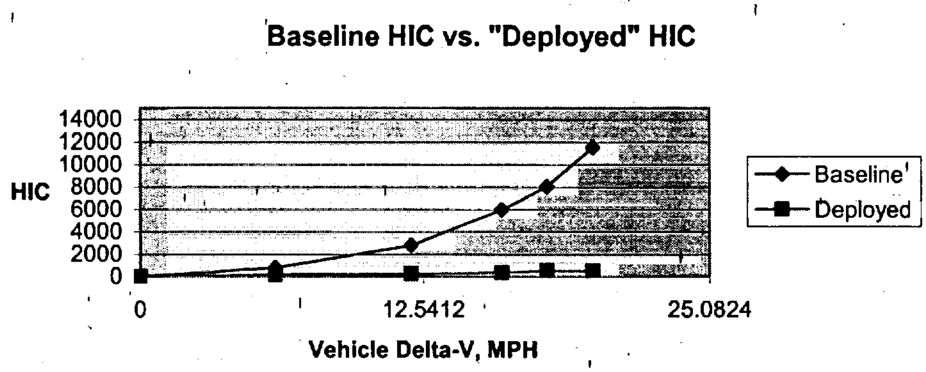


Figure B-10. Derived HIC scores plotted with vehicle delta-V (with SID-IIs)

For delta-V's greater than 20 mph (i.e., occupant delta-V of 15.4 mph), as assumed, the air bag would deflate completely with a 50th percentile test dummy. The kinetic energy associated with a 50th percentile dummy is expressed by the following equation:

$$KE = \frac{1}{2}(M_{effective})(15.4\ mph)^2$$

When $M_{effectives}$ is assumed to be an average mass of the head of the SID-H3 and the ES-2 (4.5 kg and 4.0 kg, respectively. The energy absorbed by HPS air bag would be 101 J Nm, as shown below:

$$\frac{1}{2}(M_{effective})(15.4\ mph)^2 = \frac{1}{2}(4.25\ kg)(6.884416\ m/s)^2$$

$$= 100.7\ (J)$$

Since the head of the SID-IIs (3.67 kg or 8.1 lb) is lighter than the head of 50th percentile test dummies, the air bag would bottom out at delta-V greater than 20 mph, as shown below:

Total energy absorbed by air bag:

$$\frac{1}{2}(M_{effective,\ \underline{50th}\ dummy})(15.4\ mph)^2 = \frac{1}{2}(M_{effective,\ \underline{5th}\ dummy})(V_{5th\ dummy,\ bottoming\text{-}out\ speed})^2$$

$$(4.25 \text{ kg})(6.884416 \text{ m/s})^2 = (3.6740982 \text{ kg})(V_{\text{5th dummy, bottoming-out speed}})^2$$

The bottoming-out delta-V:

$$(V_{\text{5th dummy, bottoming-out speed}})^2 = (201.43)/(3.6740982)$$

$$V_{\text{5th dummy, bottoming-out speed}} = 7.4 \text{ m/s}$$

$$= 15.8 \text{ mph}_{\text{, Occupant}} \ (20.54 \text{ mph}_{\text{, Vehicle}} \approx 21 \text{ mph})$$

The calculation above shows that the air bag would bottom out at a vehicle delta-V of 21 mph when the head of a 5th percentile dummy impacts with the air bag. Therefore, it was assumed that the air bag of the HPS bottoms out at a vehicle delta-V of 21 mph with a 5th percentile test dummy. For delta-V's greater than the bottoming out speed of 21 mph, similar to the methodology used for the 50th percentile test dummies, HIC scores were derived based on conservation of energy. The adjusted HIC scores and the corresponding profiles are shown in Table B-24 and Figure B-11, respectively.

Table B-24
Adjusted HIC Scores for Head Impacts with Pole (with SID-IIs)

Vehicle Delta-V (mph)	Occupant Delta-V at Air bag (mph)	Occupant Delta-V at Pole (mph)	Baseline HIC at Given Delta-V (at Pole)		Deployed HIC measured at Air bag	HIC measured at Pole	HIC measured with Test Dummy (based on the occupant Delta-V)
			Speed	HIC			
6	N/A	4.62	4.62	811 (1)	N/A	0	811
8	N/A	6.15	6.15	1,502	N/A	0	1,502
10	N/A	7.69	7.69	2,161	N/A	0	2,161
12	N/A	9.23	9.23	2,819	N/A	0	256
14	N/A	10.77	10.77	4,396	N/A	0	312
15	11.53	0	11.53	5,260	331	0	331
16	12.31	0	12.31	5,972	352	0	352
18	13.85	0	13.85	8,027	502	0	502
20	15.40	0	15.40	11,533	512	0	512
21	16.15	0	16.15	13,286	531	0	531
22	16.92	6.05	16.92	15,039	531	1,458 (2)	1,458
24	18.46	9.54	18.46	18,545	531	3,135	3,135
26	20.00	12.26	20.00	22,051	531	5,923	5,923

(1) At a vehicle delta-V of 5.9 mph
(2) Vehicle delta-V of 7.865 mph.

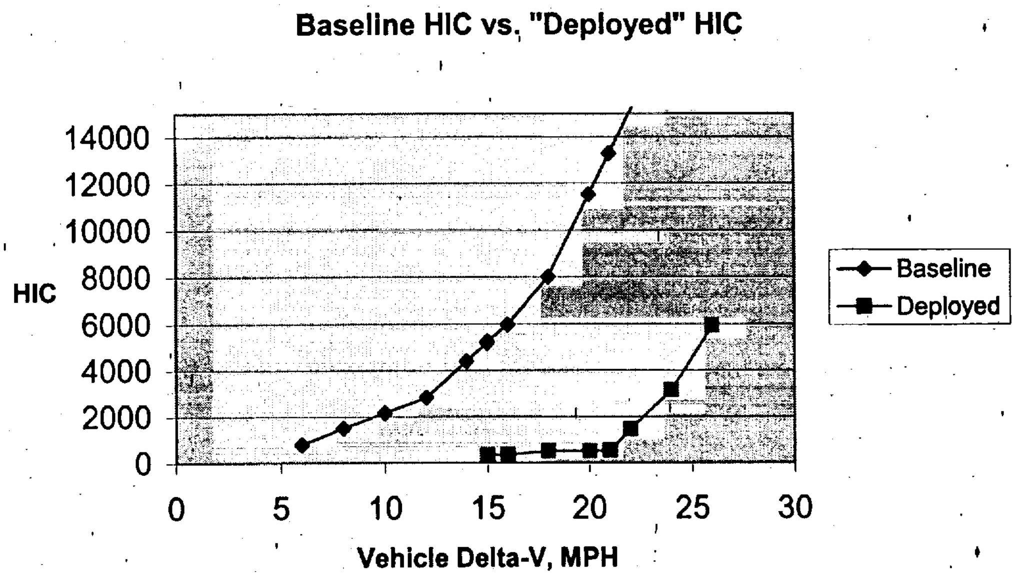


Figure B-11. Adjusted Baseline and "deployed" HIC Profiles (with SID-IIs)

Table B-25
HIC Scores for Production HPS
(with respect to Vehicle Delta-V)

Vehicle Delta-V	Baseline HIC	"Deployed" HPS Production HIC
15-16	5,972 (at 16 mph)	352 (at 16 mph)
17-18	8,027 (at 18 mph)	502 (at 18 mph)
19-20	11,533 (at 20 mph)	512 (at 20 mph)
21-22	15,039 (at 22 mph)	1,458 (at 22mph)

2.3.2 <u>Side Crashes Involving Occupant Head Impact with Vehicle Interior Components:</u>

<u>Head Injuries</u>: Since there are very limited data available for the head of the 5th test dummy impacts with vehicle interior components, test data resulting from pole tests and other tests were used as a proxy measurement for the case. During an oblique pole test performed with the SID-IIs FRG on 2002 Ford Explorer equipped with an AC HPS (curtain), the curtain did not deploy

and the head of the test dummy contacted the "intruding" side header (i.e., the area adjacent to the top of the A-pillar, NHTSA Test No. V4564). The side roof section just rearward of the A-pillar appeared to have buckled and intruded downward into the occupant compartment. The contact between the head and the interior components resulted in a HIC of 14,362. (The HIC score is similar to the baseline HIC score (of 14,242) measured with the ES-2 (i.e., 50th percentile) dummy at 20 mph in oblique pole tests.) Since the downward motion (of the buckled header toward the head) would increase relative impact speed of the head and buckling of the structure would damage the interior components., For the analysis, the HIC score of 14,362 was not used to derive the baseline HIC profile for the interior component impact case. Rather, the HIC profiles developed (for the 50th percentile dummy) for head impacts with vehicle interior components were used as a proxy measurement for the baseline and the "deployed" HIC profiles. For each delta-V range, the corresponding head injury probability was compared and the percent reduction rate and effectiveness were calculated.

2.3.3 <u>Non-Rollover Side Crashes Involving Complete Occupant Ejection:</u>

For the crash mode under consideration, similar to the assumptions used for the analysis with the SID-H3 and the ES-2 test dummies, injury levels resulting from occupant ejections would be comparable to injury levels resulting from impacts with non-deforming surfaces, such as tree or pole.

<u>Head Injuries</u>: For the baseline HIC, due to limited data, the baseline HIC profile developed for the narrow object impact (case) was used as a proxy measurement for the occupant ejection case. Although occupant ejection velocity in vehicle-to-vehicle crashes would be lower compared to vehicle-to-pole crashes at a given vehicle delta-V, as discussed previously, the baseline HIC

profile developed for the impacts with narrow objects case was used without any impact speed adjustment. For the "deployed" HIC, the HIC profile developed for the vehicle-to-pole case was used as a proxy. For the occupant ejection case, the derived HIC scores and effectiveness of HPS for head is shown in Table B-26.

Table B-26
Estimated baseline and Deployed HIC for Occupant Ejection with SID-IIs

Vehicle Delta-v (mph)	Baseline HIC	Deployed HIC
15 – 16	5,972	352
17 – 18	8,027	502
19 – 20	11,533	512
21 – 22	15,039	1,458

2.3.4 Side Crashes Involving Occupant Head Impacts with Front of Striking Vehicle:

Head Injuries: For the baseline HIC, the HIC profile developed for the impacts with narrow objects case was used. For the deployed HIC, the profile developed for the impacts with vehicle interior components case was used as a proxy measurement for the "deployed" HIC profiles, as shown in Table B-27.

Table B-27
Estimated Baseline and "Deployed" HIC for
Impacts with Striking Vehicle Case

Vehicle Delta-V	Baseline HIC[1]	"Deployed" HIC[2]
15-16 mph	5,972	281
17-18 mph	8,027	326
19-20 mph	11,533	374
21-22 mph	15,039	377

1. The HIC profile derived for the narrow object impact case, with the 5th percentile test dummy.
2. The "deployed" HIC profile derived for the vehicle-to-vehicle case.

Appendix C.

Calculation for Sales Weight Factors

To determine the sales weights for each type of head air bag system, we only include those vehicles that have a head airbag. Our estimates were based on a combination of sources. For the particular vehicles with a head/thorax airbag, we utilized the 2003 Buying a Safer Car; for the sales data, we used figures from Wards. For 2003 data, we assumed the same sales as 2002. the 2003 sales figures that were not available in Wards were either estimated or taken from the September 15, 2003 issue of *Automotive News*.

Table C-1 presents the number of head and thorax air bags by air bag type and year. Similarly, Table C-2 presents similar data, but for SUVs, Light Trucks, and Vans.

Table C-1. Passenger Cars Equipped with Head and Thorax Air Bags

Absolute Values of Head and Side Airbags for Passenger Cars							
		1999	**2000**	**2001**	**2002**	**2003**	**Total**
Passenger Cars	Thorax only	1,076,826	1,350,624	1,038,412	1,263,040	840,528	5,569,429
	AC + Thorax	98,241	126,436	649,990	796,903	1,057,167	2,728,737
	Combo	167,716	638,806	797,054	725,750	884,448	3,213,774
	AC only	0	0	38,328	123,379	130,597	292,304
	ITS + Thorax	122,973	138,834	159,154	170,519	186,280	777,760
		1,465,756	2,254,699	2,682,938	3,079,591	3,099,020	12,582,004

	1999	**2000**	**2001**	**2002**	**2003**	**Total**
Head Protection Only	0	0	38,328	123,379	130,597	292,304
Thorax Protection Only	1,076,826	1,350,624	1,038,412	1,263,040	840,528	5,569,429
Head and Thorax Protection	388,931	904,076	1,606,198	1,693,172	2,127,895	6,720,271
	1,465,756	2,254,699	2,682,938	3,079,591	3,099,020	12,582,004

Table C-2. SUVs, Light Trucks, and Vans Equipped with Head and Thorax Air Bags

Absolute Values of Head and Side Airbags for SUV, Vans, and Light Trucks							
		1999	2000	2001	2002	2003	Total
SUV, Vans, Light Truck	Thorax only	92,697	533,968	949,134	1,975,814	987,211	4,538,824
	AC + Thorax	0	0	14,983	193,480	123,248	331,710
	Combo	84,171	144,366	481,656	524,397	403,426	1,638,015
	AC only	0	0	0	46,701	389,431	436,132
	ITS + Thorax	0	16,841	39,741	43,207	51,138	150,927
		176,868	695,175	1,485,514	2,783,599	1,954,454	7,095,608

	1999	2000	2001	2002	2003	Total
Head Protection Only	0	0	0	46,701	389,431	436,132
Thorax Protection Only	92,697	533,968	949,134	1,975,814	987,211	4,538,824
Head and Thorax Protection	84,171	161,207	536,380	761,084	577,812	2,120,652
	176,868	695,175	1,485,514	2,783,599	1,954,454	7,095,608

Table C-3. Table C-1 and Table C-2 combined

Absolute Values for Passenger Cars and Light Trucks							
		1999	2000	2001	2002	2003	Total
All Body Types	Thorax only	1,169,523	1,884,592	1,987,546	3,238,854	1,827,739	10,108,253
	AC + Thorax	98,241	126,436	664,973	990,382	1,180,414	3,060,447
	Combo	251,887	783,171	1,278,710	1,250,147	1,287,874	4,851,789
	AC only	0	0	38,328	170,081	520,028	728,437
	ITS + Thorax	122,973	155,675	198,895	213,726	237,418	928,687
		1,642,624	2,949,874	4,168,452	5,863,190	5,053,473	19,677,613

	1999	2000	2001	2002	2003	Total
Head Protection Only	0	0	38,328	170,081	520,028	728,437
Thorax Protection Only	1,169,523	1,884,592	1,987,546	3,238,854	1,827,739	10,108,253
Head and Thorax Protection	473,101	1,065,282	2,142,578	2,454,255	2,705,706	8,840,923
	1,642,624	2,949,874	4,168,452	5,863,190	5,053,473	19,677,613

As mentioned before, to determine the sales weights of a particular air bag type, simply divide the number of a particular head air bag sold by the total number of vehicle sales that had a head air bag or baseline population. For 2003, this total is 3,225,734 (=1,180,414 + 1,287,874, + 520,237 + 237,418), which is for passenger cars and light duty trucks. For passenger cars, the total is 2,258,492 while for light duty trucks it is 967,243.

Table C-4 presents the weights by passenger vehicle and light duty trucks and also combining the two vehicle categories together.

Table C-4. Sales Weights by Vehicle Type and Combined

	Air Curtain Only	Air Curtain + Thorax	Combo	ITS + Thorax	Total
Passenger Cars	130,597	1,057,167	884,448	186,280	2,258,492
	5.78%	46.8%	39.2%	8.25%	100.0%
Light Duty Trucks	389,431	123,248	403,426	51,138	967,243
	40.3%	12.7%	41.7%	5.29%	100.0%
Combined	520,028	1,180,414	1,287,874	237,418	3,225,734
	16.1%	36.6%	39.9%	7.36%	100.0%

Appendix D. Expected FMVSS No. 201 Benefits at B-Pillar

Appendix D. Expected FMVSS No. 201 Benefits at B-Pillar
Expected FMVSS No. 201 benefits with padding at B-pillar: Vehicle-to-Vehicle & Others

Target population: Lateral Vehicle Delta-V of 12 -25 mph, 1997-2001 CDS, 2001 FARS, 2001 GES

Body	MAIS-1	MAIS-2	MAIS-3	MAIS-4	MAIS-5	FATAL	Total
Head	6,154	2,542	150	339	347	559	10,091
Face	4,039	35	0	0	0	48	4,122
Head & Face	10,193	2,577	150	339	347	607	14,213

Regarding fatal Injuries for the delta-V range, 15.1% of the fatalities were from B-pillar In other words, 15% of the 607 fatalities were from B-pillar, a shown below:

	Fatal
Total Fatalities	607
Fatalities from B-pillar	92

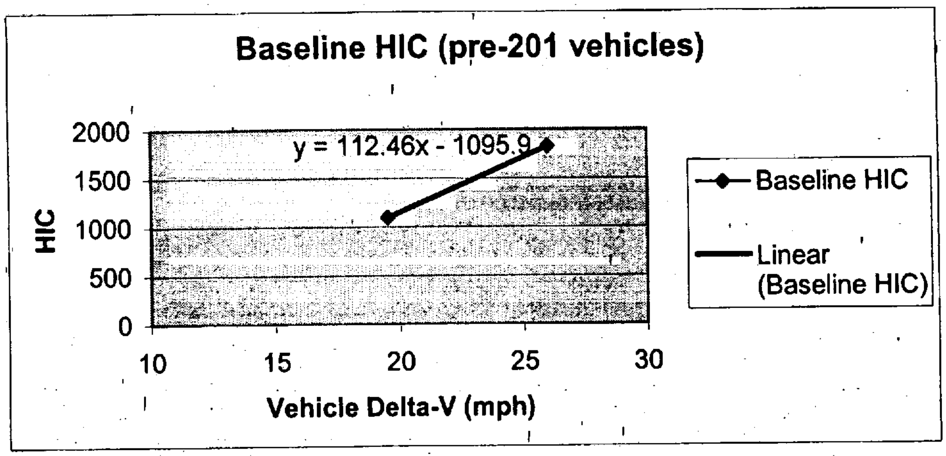
Since the fatalities from B-pillars were from pre-201 compliance vehicles, some of these fatalities would be prevented by vehicle padding (i.e., 201 countermeasures).

As part of the 201 rulemaking effort, a series of head form tests were conducted with and without padding at an occupant delta-V of 15 mph and also 20 mph. These impact speeds represent a vehicle delta-V of 19.5 mph and 26 mph, respectively. The test results are shown below:

Model	Baseline HIC at 26 mph	Baseline HIC at 19.5 mph	With Padding HIC at 26 mph	With Padding HIC at 19.5 mph
Ford Escort	1964	943		
Honda Civic	1447	796	982	
VW Golf	2777	1263	1367	858
Ford Tempo	2141	1178		
Toyota Camry	1910	972	1559	628
Ford Taurus	2363	1405	1875	879
M. Grand Marquis	1616	1057		906
Buick Electra	1662	914		
Oldsmobile Ciera		1209		
Ford Taurus	1811		1241	
Honda Civic	1224		799	
VW Golf				
Toyota Camry	1194		1091	
Honda Civic		738		
Honda Civic				
Honda Civic				
Chevrolet Caprice		1225		756
Chevrolet Caprice		1465		686
Chevrolet Caprice				
Sum	20109	13165	8914	4713
Simple Avg.	1828	1097	1273	786

The baseline HIC results show that an average HIC of 1828 and 1097 were measured at a vehicle delta-V of 19.5 mph and 26 mph, respectively. With padding, the HIC scores dropped to1273 and 786, respectively. The actual and estimated baseline HIC scores are shown below:

Speed (mph)	Baseline HIC
19.5	1097
26	1828



Based on the linear trend line, Y=112.46x-1095.9, HIC vs. Vehicle Delta-V's were estimated, as shown below:

For Pre-201 Vehicles		
Speed (mph)	Baseline HIC	Probability of Fatality
12	254	0.0000
13	366	0.0000
14	479	0.0000
15	591	0.0001
16	703	0.0002
17	816	0.0004
18	928	0.0007
19	1041	0.0014
20	1153	0.0027
21	1266	0.0052
22	1378	0.0100
23	1491	0.0189
24	1603	0.0353
25	1716	0.0652

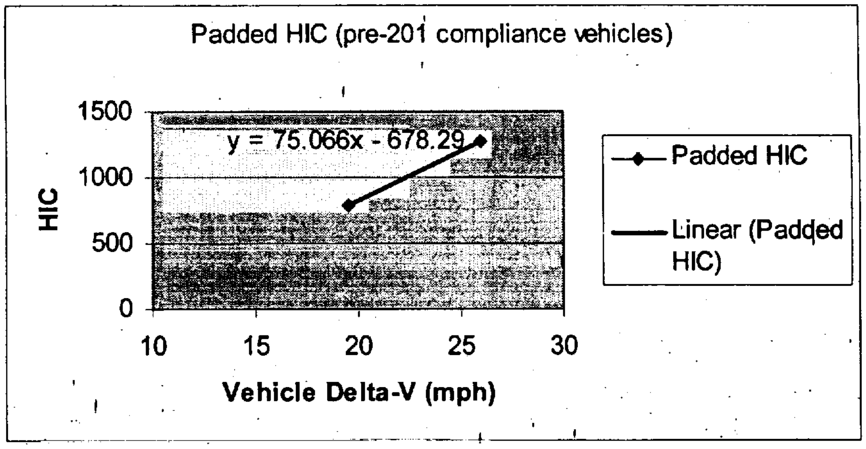
The **92** fatalities (from B-pillar, 12-25 mph) are distributed according to the fatal risk probability and injury frequency, as shown below:

Fatal Injury Distribution vs. Speed (1997-2001, CDS)	
Vehicle Delta-V	Weighted Frequency
12	0.0799
13	0.0407
14	0.2357
15	0.0138
16	0.0372
17	0.0641
18	0.0385
19	0.0471
20	0.0229
21	0.0808
22	0.1387
23	0.0162
24	0.1388
25	0.0457
Sum	1.0000

Vehicle. Delta-V (mph)	Baseline HIC	Probability of Fatality	Weighted Frequency	Fatal Probability	Weighted Probability	Fatality
12	254	0.0000	0.0799	0.0000	0.0001	0
13	366	0.0000	0.0407	0.0000	0.0001	0
14	479	0.0000	0.2357	0.0000	0.0011	0
15	591	0.0001	0.0138	0.0000	0.0001	0
16	703	0.0002	0.0372	0.0000	0.0007	0
17	816	0.0004	0.0641	0.0000	0.0024	0
18	928	0.0007	0.0385	0.0000	0.0028	0
19	1041	0.0014	0.0471	0.0001	0.0066	1
20	1153	0.0027	0.0229	0.0001	0.0062	1
21	1266	0.0052	0.0808	0.0004	0.0415	4
22	1378	0.0100	0.1387	0.0014	0.1356	12
23	1491	0.0189	0.0162	0.0003	0.0300	3
24	1603	0.0353	0.1388	0.0049	0.4809	44
25	1716	0.0652	0.0457	0.0030	0.2920	27
	Sum	0.1402	1.0001	0.0102	1.0000	**92**

Regarding the padded vehicles, the actual and estimated HIC results are shown below:

Speed (mph)	Baseline HIC
19.5	786
26	1273



For Pre-201 Vehicles		
Speed (mph)	Padded HIC	Probability of Fatality
12	223	0.0000
13	298	0.0000
14	373	0.0000
15	448	0.0000
16	523	0.0001
17	598	0.0001
18	673	0.0002
19	748	0.0003
20	823	0.0004
21	898	0.0006
22	973	0.0010
23	1048	0.0015
24	1123	0.0023
25	1198	0.0036

Effectiveness of padding:

Based on the fatality risk probability with and without padding, effectiveness of padding was derived, as shown below:

Probability of Fatality			
Speed (mph)	Baseline	Padded	Effectiveness
12	0.0000	0.0000	ineffective
13	0.0000	0.0000	ineffective
14	0.0000	0.0000	ineffective
15	0.0001	0.0000	0.6006
16	0.0002	0.0001	0.6734
17	0.0004	0.0001	0.7332
18	0.0007	0.0002	0.7823
19	0.0014	0.0003	0.8225
20	0.0027	0.0004	0.8553
21	0.0052	0.0006	0.8820
22	0.0100	0.0010	0.9037
23	0.0189	0.0015	0.9210
24	0.0353	0.0023	0.9348
25	0.0652	0.0036	0.9455

To derive lives saved by padding, the derived effectiveness (of padding) is applied to the **92** fatalities, as shown below:

Speed (mph)	Effectiveness	Fatalities	Lives Saved
12	ineffective	0	0
13	ineffective	0	0
14	ineffective	0	0
15	0.6006	0	0
16	0.6734	0	0
17	0.7332	0	0
18	0.7823	0	0
19	0.8225	1	0
20	0.8553	1	0
21	0.8820	4	3
22	0.9037	12	11
23	0.9210	3	3
24	0.9348	44	41
25	0.9455	27	25
	Sum	**92**	**85**

The results above show that padding would save **85** lives out of **92** fatalities. Thus, the **85** lives should be excluded from the 214 target population. The revised target population is shown below:

	Fatal
Total Fatalities	607
Fatalities from B-pillar	**92**
Lives Saved by Padding	85
Adjusted fatal target population	522

As for the lives saved, the saved lives need be redistributed based on the padding HIC scores at the 12-25 mph range. The saved lives were adjusted by the percent of vehicles that are already in compliance with the 201, as shown: **77**.

Appendix E. Expected FMVSS No. 201 Benefits at Roofrail

Appendix E. Expected FMVSS No. 201 Benefits at Roofrail

Expected FMVSS No. 201 Benefits with padding at Roof Rail: Vehicle-to-Vehicle & Others

Target population: Lateral Vehicle Delta-V of 12 -25 mph, 1997-2001 CDS, 2001 FARS, 2001 GES

Body	MAIS-1	MAIS-2	MAIS-3	MAIS-4	MAIS-5	FATAL	Total
Head	6,154	2,542	150	339	347	559	10,091
Face	4,039	35	0	0	0	48	4,122
Head & Face	10,193	2,577	150	339	347	607	14,213

Regarding fatal Injuries for the delta-V range, 3.3% of the fatalities were from roof side rails. In other words, 3.3% of the 607 fatalities were from roof rails, as shown below:

	Fatal
Total Fatalities	607
Fatalities from B-pillar	92

Since the fatalities from roof rails were from pre-201 compliant vehicles, some of these fatalities would be prevented by vehicle padding (or 201 countermeasures).

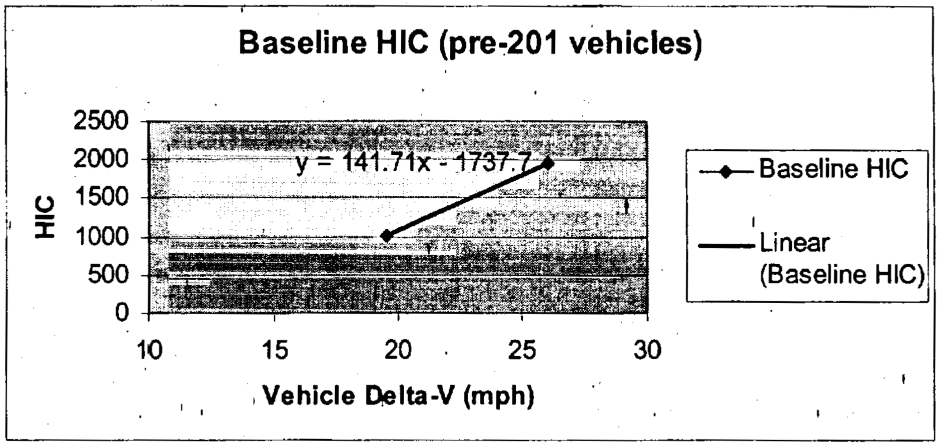
As part of the 201 rulemaking effort, a series of head form tests were conducted with and without padding at an occupant delta-V of 15 mph and also 20 mph. These impact speeds represent a vehicle delta-V of 19.5 mph and 26 mph, respectively. The test results are shown below:

Model	Baseline HIC at 26 mph	Baseline HIC at 19.5 mph	With Padding HIC at 26 mph	With Padding HIC at 19.5 mph
Ford Escort	1964	943		
Honda Civic	1447	796	982	
VW Golf	2777	1263	1367	858
Ford Tempo	2141	1178		
Toyota Camry	1910	972	1559	628
Ford Taurus	2363	1405	1875	879
M. Grand Marquis	1616	1057		906
Buick Electra	1662	914		
Oldsmobile Ciera		1209		
Ford Taurus	1811		1241	
Honda Civic	1224		799	
VW Golf				
Toyota Camry	1194		1091	
Honda Civic		738		
Honda Civic				
Honda Civic				
Chevrolet Caprice		1225		756
Chevrolet Caprice		1465		686
Chevrolet Caprice				
Sum	20109	13165	8914	4713
Simple Avg.	1828	1097	1273	786

The baseline HIC results show that an average HIC of 1947 and 1023 were measured at a vehicle delta-V of 19.5 mph and 26 mph, respectively. With padding, the HIC scores dropped to 985 and 687, respectively.

The actual and estimated baseline HIC scores are shown in below:

Speed (mph)	Baseline HIC
19.5	1026
26	1947



Based on the linear trend line, Y=141.71x-1737.7, HIC vs. Vehicle Delta-V's were estimated, as shown below:

For Pre-201 Vehicles		
Speed (mph)	Baseline HIC	Probability of Fatality
12	0	0.0000
13	105	0.0000
14	246	0.0000
15	388	0.0000
16	530	0.0001
17	671	0.0002
18	813	0.0004
19	955	0.0009
20	1097	0.0020
21	1238	0.0045
22	1380	0.0101
23	1522	0.0224
24	1663	0.0492
25	1805	0.1041

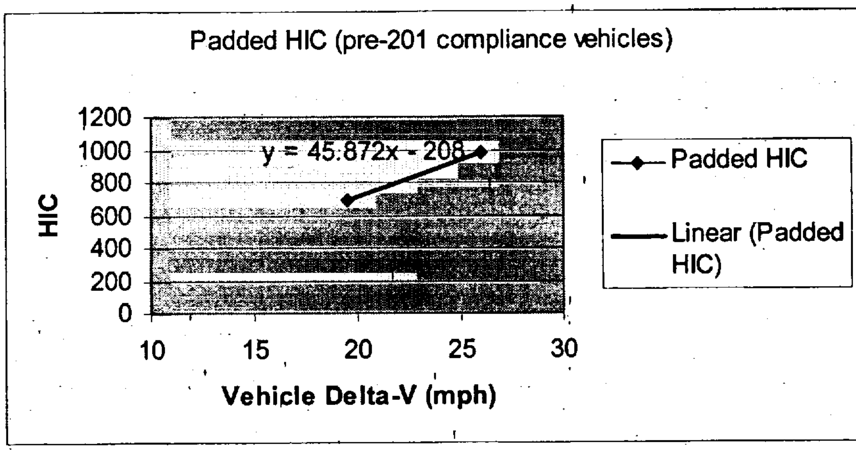
The 20 fatalities (from roof rails, 12-25 mph) are distributed according to the fatal risk probability and injury frequency, as shown below:

Fatal Injury Distribution vs. Speed (1997-2001, CDS)	
Vehicle Delta-V	Weighted Frequency
12	0.0799
13	0.0407
14	0.2357
15	0.0138
16	0.0372
17	0.0641
18	0.0385
19	0.0471
20	0.0229
21	0.0808
22	0.1387
23	0.0162
24	0.1388
25	0.0457
Sum	1.0000

Vehicle. Delta-V (mph)	Baseline HIC	Probability of Fatality	Weighted Frequency	Fatal Probability	Weighted Probability	Fatality
12	-43	0.0000	0.0799	0.0000	0.0000	0
13	100	0.0000	0.0407	0.0000	0.0000	0
14	242	0.0000	0.2357	0.0000	0.0001	0
15	384	0.0000	0.0138	0.0000	0.0000	0
16	526	0.0001	0.0372	0.0000	0.0002	0
17	668	0.0002	0.0641	0.0000	0.0007	0
18	810	0.0004	0.0385	0.0000	0.0010	0
19	952	0.0009	0.0471	0.0000	0.0029	0
20	1094	0.0020	0.0229	0.0000	0.0033	0
21	1236	0.0045	0.0808	0.0004	0.0261	1
22	1379	0.0101	0.1387	0.0014	0.1011	2
23	1521	0.0224	0.0162	0.0004	0.0263	1
24	1663	0.0492	0.1388	0.0068	0.4938	10
25	1805	0.1041	0.0457	0.0048	0.3444	7
	Sum	0.1937	1.0001	0.0138	1.0000	**20**

Regarding the padded vehicles, the actual and estimated HIC results are shown below:

Speed (mph)	Baseline HIC
19.5	687
26	985



For Pre-201 Vehicles		
Speed (mph)	Padded HIC	Probability of Fatality
12	341	0.0000
13	386	0.0000
14	431	0.0000
15	476	0.0000
16	521	0.0001
17	566	0.0001
18	611	0.0001
19	656	0.0001
20	701	0.0002
21	747	0.0003
22	792	0.0003
23	837	0.0004
24	882	0.0006
25	927	0.0007

Effectiveness of padding:

Based on the fatality risk probability with and without padding, effectiveness of padding was derived, as shown below:

Probability of Fatality			
Speed (mph)	Baseline	Padded	Effectiveness
12	0.0000	0.0000	ineffective
13	0.0000	0.0000	ineffective
14	0.0000	0.0000	ineffective
15	0.0000	0.0000	ineffective
16	0.0001	0.0001	0.0528
17	0.0002	0.0001	0.4776
18	0.0004	0.0001	0.7051
19	0.0009	0.0001	0.8315
20	0.0020	0.0002	0.9030
21	0.0045	0.0003	0.9439
22	0.0101	0.0003	0.9674
23	0.0224	0.0004	0.9808
24	0.0492	0.0006	0.9886
25	0.1041	0.0007	0.9930

To derive lives saved by padding, the derived effectiveness (of padding) is applied to the **20** fatalities, as shown below:

Speed (mph)	Effectiveness	Fatalities	Lives Saved
12	0	0	0
13	0	0	0
14	0	0	0
15	0.0000	0	0
16	0.0528	0	0
17	0.4776	0	0
18	0.7051	0	0
19	0.8315	0	0
20	0.9030	0	0
21	0.9439	1	0
22	0.9674	2	2
23	0.9808	1	1
24	0.9886	10	10
25	0.9930	7	7
	Sum	**20**	**20**

The results above show that padding would save 20 lives out of 20 fatalities. Thus, the 20 lives should be excluded from out 214 target population. The revised target population is shown below:

	Fatal
Total Fatalities	607
Fatalities from B-pillar	**20**
Lives Saved by Padding	20
Adjusted fatal target population	587

As for the lives saved, the saved lives need be redistributed based on the padding HIC scores at the 12-25 mph range. The lives saved were adjusted with the number of vehicles that are already in compliance with the 201, as shown: **18**.

Expected FMVSS No. 201 Benefits with padding at Roof Rail: Vehicle-to-Pole

Target population: Lateral Vehicle Delta-V of 12 -25 mph, 1997-2001 CDS, 2001 FARS, 2001 GES

Body	MAIS-1	MAIS-2	MAIS-3	MAIS-4	MAIS-5	FATAL	Total
Head	960	437	17	39	108	313	1874
Face	406	0	0	0	0	0	406
Head & Face	1366	437	17	39	108	313	2280

Regarding fatal Injuries for the delta-V range, 14.4% of the fatallties were from Roof Rail. In other words, 0.4% of the 607 fatalities were from B-pillar, a shown below:

	Fatal
Total Fatalities	313
Fatalities from B-pillar	45

Since the fatalities from B-pillars were from pre-201 compliance vehicles, some of these fatalities would be prevented by vehicle padding (or 201 countermeasures).

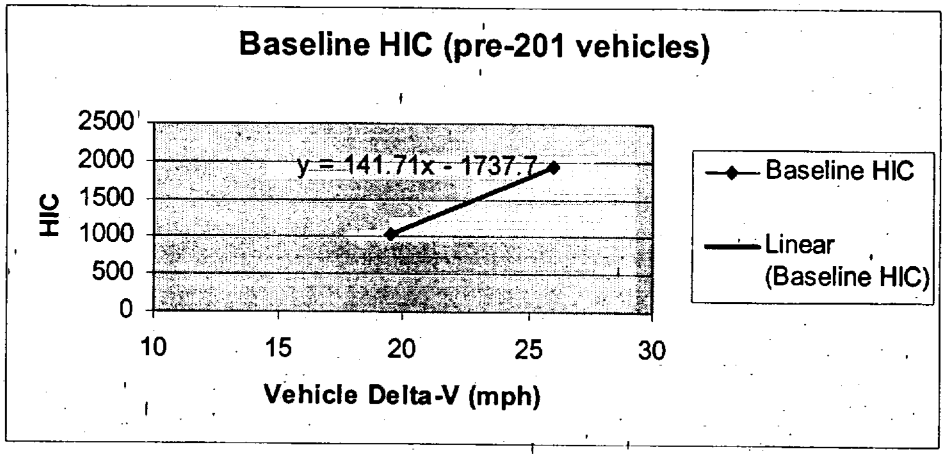
As part of the 201 rulemaking effort, a series of head form tests were conducted with and without padding at an occupant delta-V of 15 mph and also 20 mph. These impact speeds represent a vehicle delta-V of 19.5 mph and 26 mph, respectively. The test results are shown below:

Model		Baseline HIC at 26 mph	Baseline HIC at 19.5 mph		With Padding HIC at 26 mph	With Padding HIC at 19.5 mph
Ford Escort		1258	612			
Honda Civic		1687	928		947	
VW Golf		1786	718		1039	
Ford Tempo		1909	1050			
Toyota Camry		2344	1248			703
Ford Taurus		1888	716			
M. Grand Marquis		3160	1813			644
Buick Electra		1983	1091			
Oldsmobile Ciera			805			
Ford Taurus						
Honda Civic						
VW Golf						
Toyota Camry		1507			968	
Honda Civic			993			
Honda Civic						
Honda Civic						
Chevrolet Caprice			1006			692
Chevrolet Caprice			1329			707
Chevrolet Caprice						
Sum		17522	12309		2954	2746
Simple Avg.		1947	1026		985	687

The baseline HIC results show that an average HIC of 1947 and 1026 were measured at a vehicle delta-V of 19.5 mph and 26 mph, respectively. With padding, the HIC scores dropped to 985 and 687, respectively.

The actual and estimated baseline HIC scores are shown in below:

Speed (mph)	Baseline HIC
19.5	1026
26	1947



Based on the linear trend line, Y=141.71x-1737.7, HIC vs. Vehicle Delta-V's were estimated, as shown below:

For Pre-201 Vehicles		
Speed (mph)	Padded HIC	Probability of Fatality
12	0	0.0000
13	105	0.0000
14	246	0.0000
15	388	0.0000
16	530	0.0001
17	671	0.0002
18	813	0.0004
19	955	0.0009
20	1097	0.0020
21	1238	0.0045
22	1380	0.0101
23	1522	0.0224
24	1663	0.0492
25	1805	0.1041

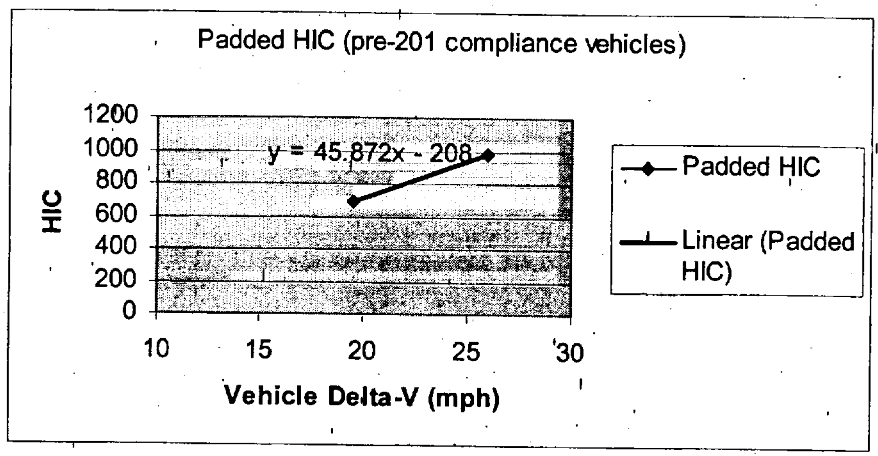
The **45** fatalities are distributed according to the fatal risk probability and injury frequency, as shown below:

Fatal Injury Distribution vs. Speed (1982-1986, in FEA FMVSS No. 201, page IV-38)	
Vehicle Delta-V	Weighted Frequency
12	0.0799
13	0.0407
14	0.2357
15	0.0138
16	0.0372
17	0.0641
18	0.0385
19	0.0471
20	0.0229
21	0.0808
22	0.1387
23	0.0162
24	0.1388
25	0.0457
Sum	1.0000

Vehicle. Delta-V (mph)	Baseline HIC	Probability of Fatality	Weighted Frequency	Fatal Probability	Weighted Probability	Fatality
12	254	0.0008	0.0799	0.0001	0.0049	0
13	366	0.0000	0.0407	0.0000	0.0000	0
14	479	0.0000	0.2357	0.0000	0.0001	0
15	591	0.0000	0.0138	0.0000	0.0000	0
16	703	0.0001	0.0372	0.0000	0.0002	0
17	816	0.0002	0.0641	0.0000	0.0007	0
18	928	0.0004	0.0385	0.0000	0.0010	0
19	1041	0.0009	0.0471	0.0000	0.0029	0
20	1153	0.0020	0.0229	0.0000	0.0033	0
21	1266	0.0045	0.0808	0.0004	0.0260	1
22	1378	0.0101	0.1387	0.0014	0.1006	5
23	1491	0.0224	0.0162	0.0004	0.0262	1
24	1603	0.0492	0.1388	0.0068	0.4914	22
25	1716	0.1041	0.0457	0.0048	0.3427	15
	Sum	0.1946	1.0001	0.0139	1.0000	45

Regarding the padded vehicles, the actual and estimated HIC results are shown below:

Speed (mph)	Padded HIC
19.5	687
26	985



For Pre-201 Vehicles		
Speed (mph)	Padded HIC	Probability of Fatality
12	341	0.0000
13	386	0.0000
14	431	0.0000
15	476	0.0000
16	521	0.0001
17	566	0.0001
18	611	0.0001
19	656	0.0001
20	701	0.0002
21	747	0.0003
22	792	0.0003
23	837	0.0004
24	882	0.0006
25	927	0.0007

Effectiveness of padding:

Based on the fatality risk probability with and without padding, effectiveness of padding was derived, as shown below:

Probability of Fatality			
Speed (mph)	Baseline	Padded	Effectiveness
12	0.0000	0.0000	ineffective
13	0.0000	0.0000	ineffective
14	0.0000	0.0000	ineffective
15	0.0000	0.0000	ineffective
16	0.0001	0.0001	0.0528
17	0.0002	0.0001	0.4776
18	0.0004	0.0001	0.7051
19	0.0009	0.0001	0.8315
20	0.0020	0.0002	0.9030
21	0.0045	0.0003	0.9439
22	0.0101	0.0003	0.9674
23	0.0224	0.0004	0.9808
24	0.0492	0.0006	0.9886
25	0.1041	0.0007	0.9930

To derive lives saved by padding, the derived effectiveness (of padding) is applied to the **45** fatalities, as shown below:

Speed (mph)	Effectiveness	Fatalities	Lives Saved
12	0.0000	0	0
13	0.0000	0	0
14	0.0000	0	0
15	0.0000	0	0
16	0.0528	0	0
17	0.4776	0	0
18	0.7051	0	0
19	0.8315	0	0
20	0.9030	0	0
21	0.9439	1	1
22	0.9674	5	4
23	0.9808	1	1
24	0.9886	22	22
25	0.9930	15	15
	Sum	**45**	**44**

The revised target population is shown below:

	Fatal
Total Fatalities	313
Fatalities from B-pillar	**45**
Lives Saved by Padding	44
Adjusted fatal target population	269

As for the lives saved, the saved lives need be redistributed based on the padding HIC scores at the 12-25 mph range. The lives saved was adjusted with the number of vehicles that are already in compliance with the 201, as shown: **40.**

The 40 lives saved by the 201 padding were redistributed by the injury probability at delta-V of 20 mph. According to the padded test results, a HIC of 701 was measured at a vehicle delta-V of 20 mph. The 40 lives saved are distributed according to the injury risk at a HIC of 701, as shown below:

HIC =	701						
	AIS 1	**AIS 2**	**AIS 3**	**AIS 4**	**AIS 5**	**FATAL**	**Total**
Probability	0.2904	0.3924	0.1946	0.0555	0.0059	0.0002	0.9390
Redistributed	11.6151	15.6922	7.7819	2.2212	0.2357	0.0076	37.5537

Appendix F. Expected FMVSS No. 201 Benefits at A-Pillar

Appendix F. Expected FMVSS No. 201 Benefits at A-Pillar
Expected FMVSS No. 201 Benefits with Padding at A-pillar: Vehicle-to-Vehicle & Others

Target population: Lateral Vehicle Delta-V of 12 -25 mph, 1997-2001 CDS, 2001 FARS, 2001 GES

Body	MAIS-1	MAIS-2	MAIS-3	MAIS-4	MAIS-5	FATAL	Total
Head	6,154	2,542	150	339	347	559	10,091
Face	4,039	35	0	0	0	48	4,122
Head & Face	10,193	2,577	150	339	347	607	14,213

Regarding fatal Injuries for the delta-V range, 4.6% of the fatalities were from A-pillar. In other words, 3.3% of the 607 fatalities were from roof rails, as shown below:

	Fatal
Total Fatalities	607
Fatalities from B-pillar	28

Since the fatalities from roof rails were from pre-201 compliance vehicles, some of these fatalities would be prevented by vehicle padding (or 201 countermeasures).

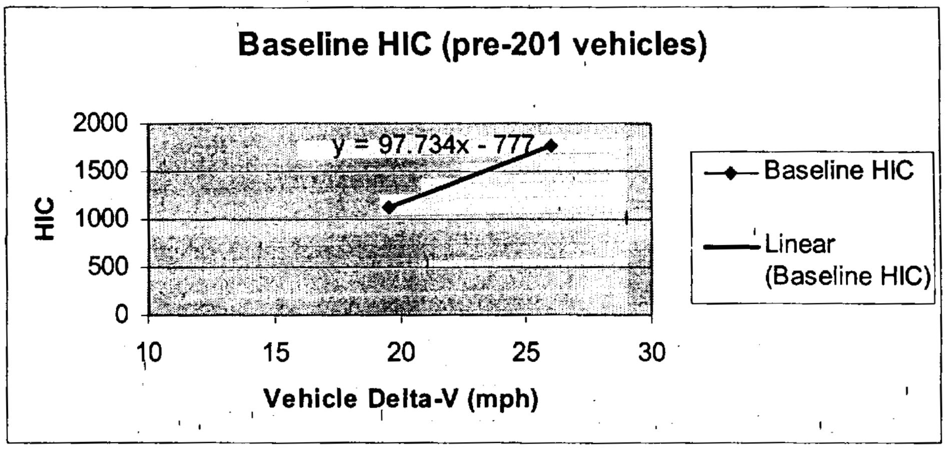
As part of the 201 rulemaking effort, a series of head form tests were conducted with and without padding at an occupant delta-V of 15 mph and also 20 mph. These impact speeds represent a vehicle delta-V of 19.5 mph and 26 mph, respectively. The test results are shown below:

Model		Baseline HIC at 26 mph	Baseline HIC at 19.5 mph		With Padding HIC at 26 mph	With Padding HIC at 19.5 mph
Ford Escort		1346	787			
Honda Civic		1837	1010		850	
VW Golf		1320	796		950	627
Ford Tempo		1979	1088			
Toyota Camry		1370	1091			818
Ford Taurus		2655	851		1301	
M. Grand Marquis		1768	981			639
Buick Electra		2849	1567			
Oldsmobile Ciera		1704	937			
Ford Taurus		2024			939	
Honda Civic		1369			908	
VW Golf		948			851	
Toyota Camry			831			
Honda Civic			1122			638
Honda Civic			1331			652
Honda Civic			1205			841
Chevrolet Caprice			1490			768
Chevrolet Caprice			1711			756
Chevrolet Caprice			1263			821
						837
	Sum	21169	18061		5799	7397
	Simple Avg.	1764	1129		967	740

The baseline HIC results show that an average HIC of 1764 and 1129 were measured at a vehicle delta-V of 19.5 mph and 26 mph, respectively. With padding, the HIC scores dropped to 967 and 740, respectively.

The actual and estimated baseline HIC scores are shown in below:

Speed (mph)	Baseline HIC
19.5	1129
26	1764



Based on the linear trend line, Y=97.734x-777, HIC vs. Vehicle Delta-V's were estimated, as shown below:

For Pre-201 Vehicles		
Speed (mph)	Baseline HIC	Probability of Fatality
12	396	0.0000
13	494	0.0001
14	591	0.0001
15	689	0.0002
16	787	0.0003
17	884	0.0006
18	982	0.0010
19	1080	0.0018
20	1178	0.0032
21	1275	0.0055
22	1373	0.0097
23	1471	0.0169
24	1569	0.0292
25	1666	0.0500

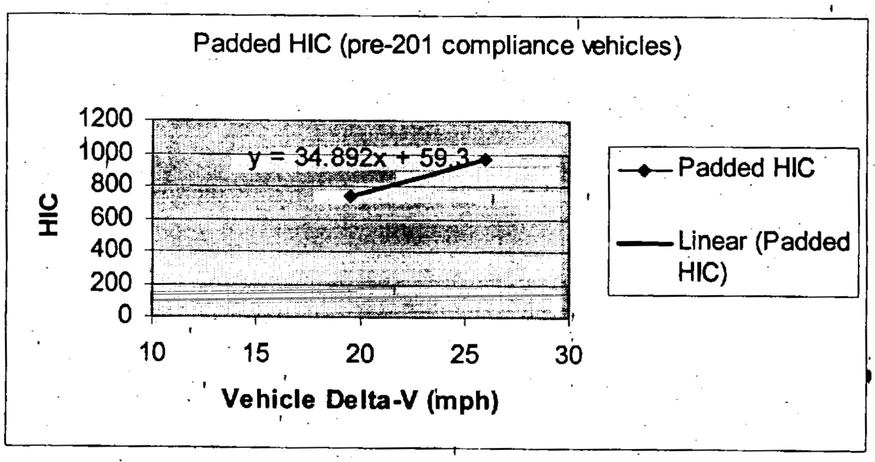
The 28 fatalities (from roof rails, 12-25 mph) are distributed according to the fatal risk probability and injury frequency, as shown below:

Fatal Injury Distribution vs. Speed (1997-2001, CDS)	
Vehicle Delta-V	Weighted Frequency
12	0.0799
13	0.0407
14	0.2357
15	0.0138
16	0.0372
17	0.0641
18	0.0385
19	0.0471
20	0.0229
21	0.0808
22	0.1387
23	0.0162
24	0.1388
25	0.0457
Sum	1.0000

Vehicle. Delta-V (mph)	Baseline HIC	Probability of Fatality	Weighted Frequency	Fatal Probability	Weighted Probability	Fatality
12	396	0.0000	0.0799	0.0000	0.0000	0
13	494	0.0001	0.0407	0.0000	0.0002	0
14	591	0.0001	0.2357	0.0000	0.0026	0
15	689	0.0002	0.0138	0.0000	0.0003	0
16	787	0.0003	0.0372	0.0000	0.0014	0
17	884	0.0006	0.0641	0.0000	0.0042	0
18	982	0.0010	0.0385	0.0000	0.0045	0
19	1080	0.0018	0.0471	0.0001	0.0097	0
20	1178	0.0032	0.0229	0.0001	0.0083	0
21	1275	0.0055	0.0808	0.0004	0.0516	1
22	1373	0.0097	0.1387	0.0013	0.1550	4
23	1471	0.0169	0.0162	0.0003	0.0315	1
24	1569	0.0292	0.1388	0.0040	0.4672	13
25	1666	0.0500	0.0457	0.0023	0.2634	7
	Sum	0.1184	1.0001	0.0087	1.0000	**28**

Regarding the padded vehicles, the actual and estimated HIC results are shown below:

Speed (mph)	Baseline HIC
19.5	740
26	967



For Pre-201 Vehicles		
Speed (mph)	Padded HIC	Probability of Fatality
12	478	0.0000
13	513	0.0001
14	548	0.0001
15	583	0.0001
16	618	0.0001
17	652	0.0001
18	687	0.0002
19	722	0.0002
20	757	0.0003
21	792	0.0003
22	827	0.0004
23	862	0.0005
24	897	0.0006
25	932	0.0008

Effectiveness of padding:

Based on the fatality risk probability with and without padding, effectiveness of padding was derived, as shown below:

	Probability of Fatality		
Speed (mph)	Baseline	Padded	Effectiveness
12	0.0000	0.0000	0.0000
13	0.0001	0.0001	0.0000
14	0.0001	0.0001	0.2386
15	0.0002	0.0001	0.4799
16	0.0003	0.0001	0.6413
17	0.0006	0.0001	0.7511
18	0.0010	0.0002	0.8267
19	0.0018	0.0002	0.8789
20	0.0032	0.0003	0.9152
21	0.0055	0.0003	0.9405
22	0.0097	0.0004	0.9581
23	0.0169	0.0005	0.9704
24	0.0292	0.0006	0.9790
25	0.0500	0.0008	0.9849

To derive lives saved by padding, the derived effectiveness (of padding) is applied to the **28** fatalities, as shown below:

Speed (mph)	Effectiveness	Fatalities	Lives Saved
12	0.0000	0	0
13	0.0000	0	0
14	0.2386	0	0
15	0.4799	0	0
16	0.6413	0	0
17	0.7511	0	0
18	0.8267	0	0
19	0.8789	0	0
20	0.9152	0	0
21	0.9405	1	1
22	0.9581	4	4
23	0.9704	1	1
24	0.9790	13	13
25	0.9849	7	7
	Sum	**28**	**27**

The revised target population is shown below:

	Fatal
Total Fatalities	607
Fatalities from B-pillar	**28**
Lives Saved by Padding	27
Adjusted fatal target population	580

As for the lives saved, the saved lives need be redistributed based on the padding HIC scores at the 12-25 mph range. The lives saved were adjusted with the number of vehicles that are already in compliance with the 201, as shown: **24**.

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. Leadtime is the last section of this chapter. 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 needed to pass the proposed tests and that most 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 proposing 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 that side head and thorax air bags will be sufficient to meet the proposed test, so costs for structural changes and padding countermeasures are not included in the cost estimate for this proposal.

A. Current Side Air Bag Technology Costs (in 2002 Dollars)

Several cost estimates come from two NHTSA contractor teardown studies of side air bags[1]. Based on these studies, we estimate the current window curtain head air bag costs $122[2] per vehicle (for two). The current thorax air bags are estimated to cost about $61 per vehicle (for two)[3]. The current combination head/thorax air bags[4] are estimated to cost $73 per vehicle (for two). Side impact sensors are estimated to cost $35 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 ($70). Changes to the frontal electronic control module to add side impact sensor signals and necessary wiring are estimated to cost about $3. Thus, the total cost to a vehicle for two current separate thorax side air bags and head window curtains is estimated to be $221 ($61 for the thorax bags, $122 for the window curtain air bag system, $35 for the sensors and $3 to connect to the already existing electronic control module). The total cost to a vehicle for two current combination head/thorax air bags is $111 ($73 for the

---

[1] "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.

[2] Taking variable manufacturing costs of $38.22*1.51 to mark it up to consumer costs * 1.057 to go from 1999 economics to 2002 economics * 2 per vehicle = $122.00.

[3] This estimate is based on the average cost estimates of the 2001 Chevrolet Suburban and the 2001 Lexus RX 300 thorax air bags.

[4] This estimate is based on the average cost estimates of the 2001 Lincoln Town Car and the 2001 Chrysler Town and Country minivan combination head/thorax air bags.

combination head/thorax bags, $35 for the sensors and $3 to connect to the already existing electronic control module).

1. Size of the Air Bag

The agency believes 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 head air bags designed to comply with the FMVSS No. 201 optional pole test and currently available thorax air bags. 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 around $3 per vehicle for additional air bag fabric and additional inflator capability.

Table VI-1. Curtain and Side Air bag System Consumer Costs
(in 2002 dollars)[5]

Air Bag System (one)	**Air Bag Material**	**Inflator**
Volvo Curtain Head Air Bag Assembly	$18.94	$21.00

[5] The costs in this table were increased from 1999 economics to 2002 economics using the Gross Domestic Product implicit price deflator. 2002 = 110.66, 1999 = 104.69, 110.66/104.69 = 1.057. 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.

Based on the pole test results, most of the current combo and thorax air bags are not large enough to comply with the proposed requirements. 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 bollard. 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.

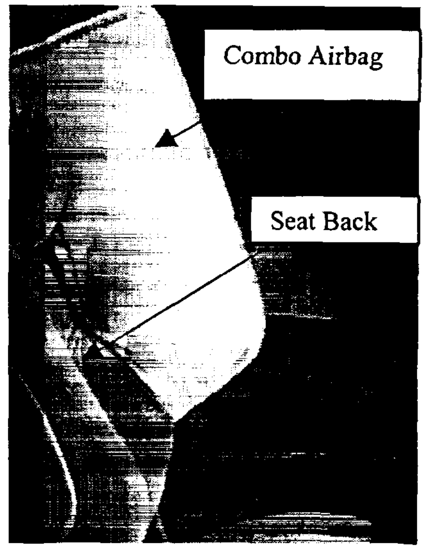


Figure 1. Side Impact "Combo" Airbag

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 propellants and a larger casing to house the propellants 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. We estimate that a slight increase in width will be needed to pass the test and will cost about $5 per vehicle. The two combination head/thorax air bags in the cost teardown study were wide enough in the head area, but one was not wide enough (again 12 inches wide) in the thorax area. In our oblique pole testing of other systems, we have seen the need to make both the thorax and head areas wider for the oblique test. Thus, we estimate a cost increase of about $10 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 2002 Economics)

Air Bag Electronics	**BMW 5-Series Front and Side**	**BMW Z3 Front Only**	**Difference in Retail Price**
Electronic Control Module	$168.61	$165.29	$3.32

The results in Table VI-2 show that the increase in cost ($3.32) 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 side impact sensors raise an interesting methodology issue for the agency. The proposed oblique pole test is aimed at the front seat dummy, so the proposal 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 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 would like the manufacturers to move toward 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 perpendicular 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 all the impact scenarios that we would want the air bag to deploy. 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 claiming 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. 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. Three of the cost estimates were similar at $35, $40, and $43. The agency can't understand why the side impact sensor costs would be much more than a frontal impact sensor. Based on the "Final Economic Assessment, FMVSS No. 208 Advanced Air Bags," Table VII-2, the cost of two additional sensors for the offset frontal test was $24.20 per vehicle in 2002 dollars (when the cost is adjusted with the Gross Domestic Product implicit price deflator).

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, and to assume the cost of side impact sensors will be $35 for two sensors to $70 for four sensors per vehicle. Some of the current vehicles with side window curtain air bags currently have two sensors and some have four sensors. We will assume that 50 percent of the current vehicles with side window curtains have two sensors and 50 percent have four sensors.

4. Estimated Vehicle Costs for Meeting Oblique Pole Test. Table VI-3 shows our range of cost estimates, although there is no guarantee that these technologies are the ones that will 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 proposal. The actual and estimated costs are shown in Table VI-3.

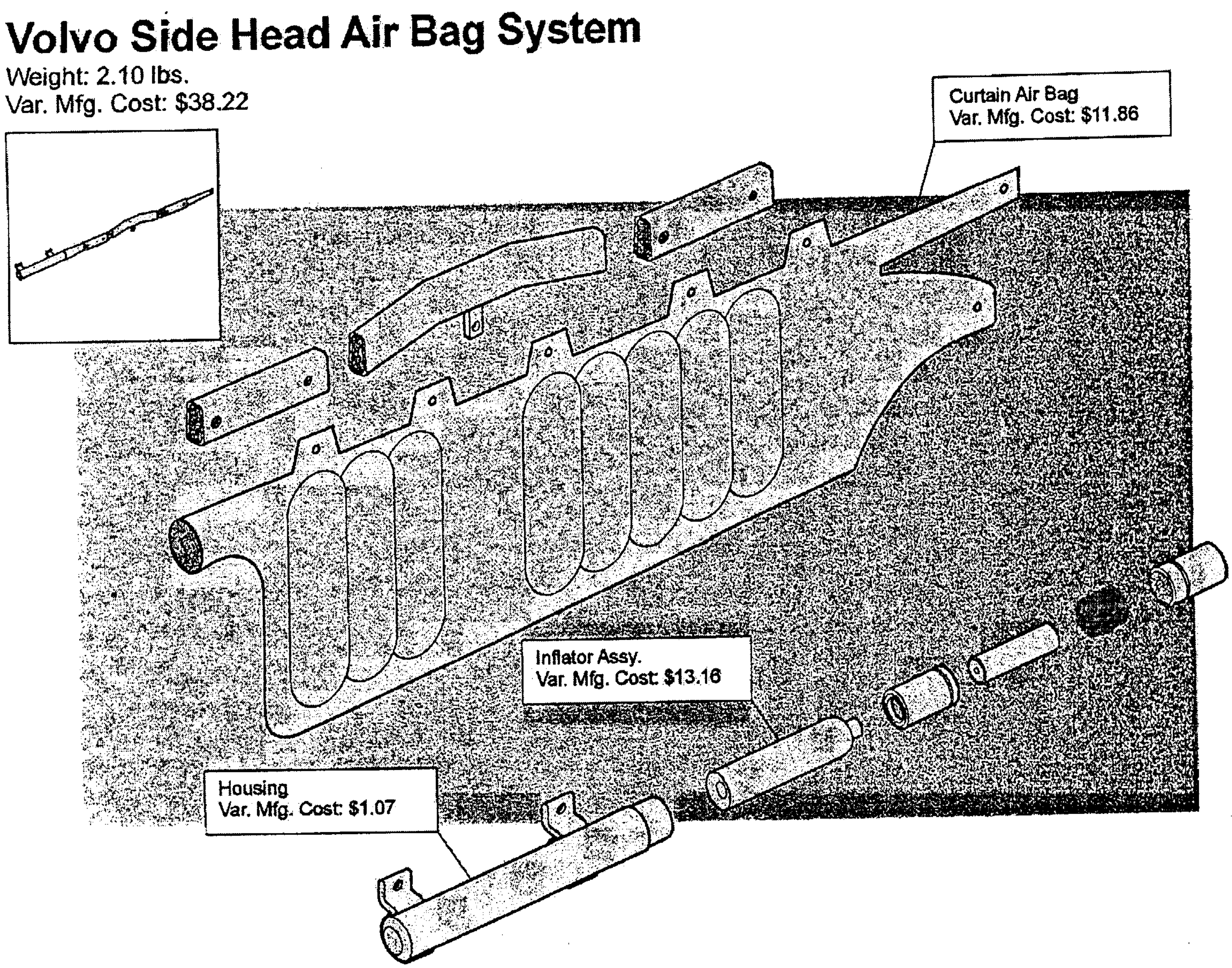


Figure 2. Volvo Side Head Air Bag System

Table VI-3. Technology Cost Summary (in 2002 dollars) Per Vehicle

Air Bag Type	Air Bag	ECM Costs	Sensor Costs (2)	Sensor Costs (4)	Total Cost
Combo (Com)	$73				
Wider Combo (W-Com)	$83				
Thorax (Th)	$61				
Wider Thorax (W-Th)	$66				
Curtain (Cu)	$122				
Wider Curtain (W-Cu)	$125				
System Type					
Combo (Com)	$73	$3	$35		$111
Wider Combo (W-Com)	$83	$3	$35		$121
Current Curtain Plus Thorax (2 sensor)	$183	$3	$35		$221
Wider Curtain Plus Wider Thorax (2 sensor)	$191	$3	$35		$229
Current Curtain Plus Thorax (4 sensor)	$183	$3		$70	$256
Wider Curtain Plus Wider Thorax (4 sensor)	$191	$3		$70	$264

In 2002, a total of 17,226,833 passenger cars and light trucks were sold in U.S. We used the MY 2003 data on specific make/models from the "Buying a Safer Car" guide and the sales data for those models from 2002 sales and estimated for MY 2003 the percent of vehicles equipped with head and thorax side air bags, as 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).

Table VI-4

Vehicles Equipped with Head and Thorax Side Air Bags

System	Estimated Percent of MY 2003 Sales[6]
Thorax Only	10.61%
Curtain Plus Thorax	6.85
Combination	7.48
Curtain Only	3.02
ITS Plus Thorax	1.38
Head Subtotal	18.73%
Thorax Subtotal	26.32%
Any System Subtotal	29.34%

Table VI-4 shows that based on 2002 sales and 2003 MY availability of head and thorax side air bag, an estimated 18.73 percent of the passenger cars and SUV & light trucks are equipped with head air bags, whereas 26.32 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	70.66%	(1) New W-Combo or
		(2) New W-Cu + New W-Th
Curtain + Thorax	6.85%	W-Cu + W-Th
Curtain	3.02%	W-Cu + New W-Th
Combo	7.48%	W-Combo
Thorax	10.61%	(1) New W-Combo or
		(2) New W-Cu + W-Th
ITS + Thorax	1.38%	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

[6] In determining the percent of the MY 2003 vehicles with side air bags, we assumed a sales rate of 20% for those systems offered as an option. 20% is based on confidential data supplied to NHTSA for compliance testing.

As shown in Table VI-5 and used throughout the analysis, the agency analyzed two ways that manufacturers that don't already 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. The wider combo bag appears less expensive. There are a few different reasons that the manufacturers might choose the more expensive wider window curtain and wider thorax air bag designs:

1) The agency has announced its intentions to have an ejection mitigation rulemaking, which may push designs to window curtains.
2) A wider combo air bag will have to cover more area, be much bigger, require a larger inflator, and might now be too aggressive to meet the voluntary out-of-position side air bag testing developed by the Technical Working Group (TWG).

Compliance Rate of Current Air Bags with the Proposal

The pole test results indicate that most vehicles with current side thorax air bags, combination bags, or window curtains would not meet the proposed oblique pole requirements. Based on information collected in the benefits chapter, we estimate that about 12 percent of the current air bags in the MY 2003 fleet would pass the proposed test.

Total Costs

Table VI-6 show the costs for manufacturers to meet the proposed requirements, broken down by the types of countermeasure systems currently in use. The results in Tables VI-6 show that the total annual net cost for meeting the proposal with a combination head/thorax air bag are estimated to be $1.6 billion. If manufacturers choose to use window curtains and thorax air bags with 2 sensors, the cost are $3.0 billion. If manufacturers choose to use window curtains and thorax air bags with 4 sensors, the costs are estimated to be $3.6 billion annually. The average incremental cost per vehicle with a combination head/thorax air bag is estimated to be $91 per vehicle. If manufacturers choose to use window curtains and thorax air bags with 2 sensors, the average incremental costs are estimated to be $177 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 $208 per vehicle

Table VI-6
Total Costs and Average Vehicle Costs*

	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	$1.563 billion	$3.043 billion	$3.580 billion
Average Incremental Cost per Vehicle	$91	$177	$208

* See Appendix VI-a for detailed cost calculations

It should be noted that the costs above in Table VI-6 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 proposed requirements, because the NPRM proposes a four-year leadtime, followed by a phase-in schedule for gradually implementing the new requirements. 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 proposed 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 proposed requirements.

B. Other Potential Technology Cost

Although the majority of the manufacturers will install air bags to comply with the proposed 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-7 and -8. 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-8.

Table VI-7
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-8.
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-7, 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 \$0.045 for one square inch of one inch thick polyurethane padding[7]. One and one-half inch padding would cost \$0.056 per square inch. If a one-inch thick pad

[7] 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 2002 economics using the gross domestic product implicit price deflator (110.66/94.05 = 1.177). Thus, the cost in 2002 economics is \$0.038*1.177 = \$0.045 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 \$0.056 in 2002 economics (\$0.048*1.177).

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 $8.64 per door (192*$0.045) or $17.28 for two doors.

C. Compliance Test Costs

This section discusses the estimated costs for the agency or a manufacturer to perform compliance tests. Costs are in 2002 dollars.

Currently the agency performs FMVSS 214 moving deformable barrier (MDB) tests with 50th percentile male SID dummies. If a manufacturer chooses the FMVSS 201 optional pole test, then it is tested with the 50th percentile SID-HIII dummy.

The proposal will increase the test options to the agency. The MDB test can be performed with both the 50th percentile male dummy and the 5th percentile female dummy. The FMVSS 214 oblique pole test can be performed with the 50th percentile male dummy and the 5th percentile female dummy. The agency is proposing to 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 propose to increase the certification requirements of the standards from one required and one optional test to four 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 proposed 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 $20,000 (not including the cost of the vehicle). The cost of running a pole test (either the FMVSS No. 201 optional 90-degree or the proposed 75-degree oblique) is around $16,000. The average cost of a vehicle is $21,000. Thus, the total cost for a MDB test, including the vehicle, is $41,000 and the average cost for running a pole test is $37,000.

Typically, the agency would select one MDB test and one pole test to perform on a vehicle. However, manufacturers have to certify to all four 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 they ran all four tests, the compliance costs would be $156,000, compared to the current requirement for one test at $41,000, for an increase of $115,000 pre make/model.

The vehicle cost estimates for NHTSA may not reflect the vehicle cost estimates for manufacturers. While the average new vehicle price is around $21,000, manufacturers developing all new models may decide to use a few prototype vehicles for development testing purpose. A prototype vehicle can cost much more than a production vehicle. As discussed, 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.

D. Leadtime

As shown previously, the manufacturers have voluntarily installed several different countermeasures. In a press release dated December 4, 2003, the Alliance of Automobile Manufacturers stated "To enhance safety in front-to-side crashes, automakers commit to enhance protection for passenger car and light truck occupants in side-struck vehicles, principally through head protection. ... By September 1, 2007, at least 50 percent of all vehicles offered in the U.S. by participating manufacturers will meet the front-to-side performance criteria, and by September 2009, 100 percent of the vehicles of participating manufacturers will meet the criteria." The Alliance did not specify which countermeasures would be used, but stated "through the use of features such as side airbags, airbag curtains and revised side impact structures." This indicates a commitment to side impact safety in a similar time frame as the agency's proposal

Based on this proposal, the manufacturers would have to test their vehicles with this new oblique pole test and determine whether they need changes in their current countermeasures, whether they will need additional sensors, etc. The longest design issue, in terms of time, is installing a window curtain on the side roof rail. This is accomplished easiest when the model is being redesigned. Most passenger car models are redesigned in a 4-5 year period, while pickup trucks and some vans have longer redesign cycles of 6-7 years. NHTSA believes the most cost-effective way to accomplish this redesign task is to allow a phase-in of the requirements. This accomplishes two objectives. First, the new make/models can be designed with the new countermeasure efficiently. Second, all of the make/models don't have to be redesigned at one time.

For the oblique pole test, the agency is proposing a phase-in schedule starting the first September 1, 4 years after publication of the final rule. The proposed phase-in schedule is 20 percent of a manufacturer's light vehicles in the 5^{th} year, 50 percent in the 6^{th} year, and all vehicles in the 7^{th} year after publication of the final rule. Credits will be allowed for early compliance, applicable to the 20 percent and 50 percent phase-in requirements.

As with previous rules, the agency will allow manufacturers that produce three or fewer lines the option of omitting the first year of the phase-in, if they achieve full compliance in the second year. Furthermore, vehicles manufactured in two or more stages do not have to comply until all vehicles have to comply.

For the new requirements for the moving deformable barrier (MDB) test, using the ES-2re and the SID-IIs dummies, the agency is proposing an effective date on the first September 1, four years after publication of the final rule. Countermeasures for the dynamic test are well known by this time and shouldn't cause large redesigns of the side of the car. Thus, the agency believes that the leadtime needed for the MDB tests are less than those needed for the oblique pole test.

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 $
		35	70	3.32	122	125	3	61	66	5	73	83	10	
Current	**Needs**													
No air bag	Wcu, Wth, 2sen, hook	35		3.32		125			66					229.32
Curtain +thorax	c(incr), t(incr)						3			5				8
Curtain	c(incr), Wth.						3		66					69
Combo	Combo(incre)												10	10
Thorax	Wcu, t(incre),					125				5				130
ITS + Thorax	t(incre)									5				5

	Percent of MY 2003 Sales	Total Sales 17226833	1- % Current Compliance		Total Cost Millions	Average Cost Per Vehicle
No air bag	0.7066	12172480	1	12172480	2791.393	
Curtain +Thorax	0.0685	1180038	0.88	1038433	8.307468	
Curtain	0.0302	520250.4	0.88	457820.3	31.5896	
Combo	0.0748	1288567	0.88	1133939	11.33939	
Thorax	0.1061	1827767	0.84	1535324	199.5922	
ITS + Thorax	0.0138	237730.3	0.88	209202.7	1.046013	
	1	17226833		16547200	3043.268	176.65

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 $
		35	70	3.32	122	125	3	61	66	5	73	83	10	
Current	**Needs**													
No air bag	Wcu, Wth, 2sen, hook	35		3.32								83		121.32
Curtain +thorax	c(incr), t(incr)						3			5				8
Curtain	c(incr), Wth.						3		66					69
Combo	Combo(incre)												10	10
Thorax	Wcu, t(incre),												22	22
ITS + Thorax	t(incre)									5				5

	Percent of MY 2003 Sales	Total Sales 17226833	1- % Current Compliance		Total Cost Millions	Average Cost Per Vehicle
No air bag	0.7066	12172480	1	12172480	1476.765	
Curtain +Thorax	0.0685	1180038	0.88	1038433	8.307468	
Curtain	0.0302	520250.4	0.88	457820.3	31.5896	
Combo	0.0748	1288567	0.88	1133939	11.33939	
Thorax	0.1061	1827767	0.84	1535324	33.77713	
ITS + Thorax	0.0138	237730.3	0.88	209202.7	1.046013	
	1	17226833		16547200	1562.825	90.72

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 $
		35	70	3.32	122	125	3	61	66	5	73	83	10	
Current	**Needs**													
No air bag	Wcu, Wth, 2sen, hook		70	3.32		125			66					264.32
Curtain +thorax	c(incr), t(incr)	35					3			5				43
Curtain	c(incr), Wth.	35					3		66					104
Combo	Combo(incre)												10	10
Thorax	Wcu, t(incre),	35				125				5				165
ITS + Thorax	t(incre)												22	22

	Percent of MY 2003 Sales	Total Sales 17226833	1- % Current Compliance		Total Cost Millions	Adjusted for 476,300 Vehicles With 4-Sensors @$35 -16.67 mil.	Average Cost Per Vehicle	Adjusted for 476,300 Vehicles With 4-Sensors
No air bag	0.7066	12172480	1	12172480	3217.43			
Curtain +Thorax	0.0685	1180038	0.88	1038433	49.6088			
Curtain	0.0302	520250.4	0.88	457820.3	49.79836			
Combo	0.0748	1288567	0.88	1133939	11.33939			
Thorax	0.1061	1827767	0.84	1535324	263.564			
ITS + Thorax	0.0138	237730.3	0.88	209202.7	4.602459			
	1	17226833		16547200	3596.343	3579.673	208.76	207.80

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 $
		35	70	3.32	122	125	3	61	66	5	73	83	10	
Current	**Needs**													
No air bag	Wcu, Wth, 2sen, hook	35		3.32	122			61						221.32
Curtain +thorax	c(incr), t(incr)													0
Curtain	c(incr), Wth.							61						61
Combo	Combo(incre)													0
Thorax	Wcu, t(incre),				122									122
ITS + Thorax	t(incre)													0

	Percent of MY 2003 Sales	Total Sales 17226833	1- % Current Compliance		Total Cost Millions	Average Cost Per Vehicle
No air bag	0.7066	12172480	1	12172480	2694.013	
Curtain +Thorax	0.0685	1180038	0.88	1038433	0	
Curtain	0.0302	520250.4	0.88	457820.3	27.92704	
Combo	0.0748	1288567	0.88	1133939	0	
Thorax	0.1061	1827767	0.84	1535324	187.3096	
ITS + Thorax	0.0138	237730.3	0.88	209202.7	0	
	1	17226833		16547200	2909.25	168.87

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 $
		35	70	3.32	122	125	3	61	66	5	73	83	10	
Current	Needs													Total $
No air bag	Wcu, Wth, 2sen, hook	35		3.32							73			111.32
Curtain +thorax	c(incr), t(incr)													0
Curtain	c(incr), Wth.							61						61
Combo	Combo(incre)													0
Thorax	Wcu, t(incre),												12	12
ITS + Thorax	t(incre)													0

	Percent of MY 2003 Sales	Total Sales 17226833	1- % Current Compliance		Total Cost Millions	Average Cost Per Vehicle
No air bag	0.7066	12172480	1	12172480	1355.04	
Curtain +Thorax	0.0685	1180038	0.88	1038433	0	
Curtain	0.0302	520250.4	0.88	457820.3	27.92704	
Combo	0.0748	1288567	0.88	1133939	0	
Thorax	0.1061	1827767	0.84	1535324	18.42389	
ITS + Thorax	0.0138	237730.3	0.88	209202.7	0	
	1	17226833		16547200	1401.391	81.35

TABLE VIa-6
OBLIQUE 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 $
		35	70	3.32	122	125	3	61	66	5	73	83	10	
Current	**Needs**													Total $
No air bag	Wcu, Wth, 2sen, hook						3			5				8
Curtain +thorax	c(incr), t(incr)						3			5				8
Curtain	c(incr), Wth.						3			5				8
Combo	Combo(incre)												10	10
Thorax	Wcu, t(incre),						3			5				8
ITS + Thorax	t(incre)									5				5

	Percent of MY 2003 Sales	Total Sales 17226833	1- % Current Compliance		Total Cost Millions	Average Cost Per Vehicle
No air bag	0.7066	12172480	1	12172480	97.37984	
Curtain +Thorax	0.0685	1180038	0.88	1038433	8.307468	
Curtain	0.0302	520250.4	0.88	457820.3	3.662563	
Combo	0.0748	1288567	0.88	1133939	11.33939	
Thorax	0.1061	1827767	0.84	1535324	12.28259	
ITS + Thorax	0.0138	237730.3	0.88	209202.7	1.046013	
	1	17226833		16547200	134.0179	7.77

TABLE VIa-7 OBLIQUE 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 $
		35	70	3.32	122	125	3	61	66	5	73	83	10	
Current	Needs													
No air bag	Wcu, Wth, 2sen, hook												10	10
Curtain +thorax	c(incr), t(incr)						3			5				8
Curtain	c(incr), Wth.						3			5				8
Combo	Combo(incre)												10	10
Thorax	Wcu, t(incre),												10	10
ITS + Thorax	t(incre)									5				5

	Percent of MY 2003 Sales	Total Sales 17226833	1- % Current Compliance		Total Cost Millions	Average Cost Per Vehicle
No air bag	0.7066	12172480	1	12172480	121.7248	
Curtain +Thorax	0.0685	1180038	0.88	1038433	8.307468	
Curtain	0.0302	520250.4	0.88	457820.3	3.662563	
Combo	0.0748	1288567	0.88	1133939	11.33939	
Thorax	0.1061	1827767	0.84	1535324	15.35324	
ITS + Thorax	0.0138	237730.3	0.88	209202.7	1.046013	
	1	17226833		16547200	161.4335	9.37

TABLE VIa-8
OBLIQUE TEST ONLY
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 $
		35	70	3.32	122	125	3	61	66	5	73	83	10	
Current	**Needs**													
No air bag	Wcu, Wth, 2sen, hook	35					3			5				43
Curtain +thorax	c(incr), t(incr)	35					3			5				43
Curtain	c(incr), Wth.	35					3			5				43
Combo	Combo(incre)												10	10
Thorax	Wcu, t(incre),	35					3			5				43
ITS + Thorax	t(incre)													0

	Percent of MY 2003 Sales	Total Sales 17226833	1- % Current Compliance		Total Cost Millions	Adjusted for 476,300	Average Cost Per Vehicle	Adjusted for 476,300
						Vehicles		Vehicles
						With		With
No air bag	0.7066	12172480	1	12172480	523.4166	4-Sensors @$35		4-Sensors
Curtain +Thorax	0.0685	1180038	1	1180038	50.74164	-16.67 mil.		
Curtain	0.0302	520250.4	1	520250.4	22.37077			
Combo	0.0748	1288567	1	1288567	12.88567			
Thorax	0.1061	1827767	1	1827767	78.59398			
ITS + Thorax	0.0138	237730.3	1	237730.3	0			
	1	17226833		17226833	688.0087	671.34	39.94	38.97

VII. COST-EFFECTIVENESS AND BENEFIT-COST ANALYSES

A. Cost –Effectiveness Analysis

The intent of the proposed rulemaking is to minimize injuries in side crashes. To achieve this goal, NHTSA is proposing a new pole test that is based on the FMVSS No. 201 optional pole test to ensure that occupants are better protected under non-rollover side crash environments.

An oblique pole test is proposed to enhance head and side air bag benefits. The oblique pole test would be conducted for both 50th male and 5th female dummies. Three countermeasures were examined for costs and benefits. We will show the methodology for the combination head/thorax side air bag, and then the results for the window curtain thorax air bag countermeasures.

As a primary measure of the impact of the proposed 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 countermeasure)

Injury Severity	No. of Fatalities and Injuries	Conversion Factor	Equivalent Fatalities (Undiscounted)
Fatalities	686	1.0	686
AIS-5	291	0.7124	207
AIS-4	362	0.2153	78
AIS-3	227	0.0916	21
AIS-2	865	0.0458	40
AIS-1	-1,274	0.0031	-4
Total			1,028

The results in Table VII-1 show that the combination head/thorax side air bags would save 1,028 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

Fatal Equivalent	Discount Rate[1]	Discounted Fatal Equivalent
1,028	0.8373 at 3%	860
1,028	0.6832 at 7%	702

The discounted fatal equivalents in Table VII-2 show that head and side air bags would save 860 and 702 equivalent lives when discounted at 3% and 7%, respectively.

For the net cost, 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 net 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	$1,563	860 (at 3%)	$1.8 million
		702 (at 7%)	$2.2 million
Curtain and Thorax air bags (2 Sensor)	$3,043	1,176 (at 3%)	$2.6 million
		960 (at 7%)	$3.2 million
Curtain and Thorax air bags (4 Sensor)	$3,580	1,183 (at 3%)	$3.0 million
		965 (at 7%)	$3.7 million

[1] The 3% discount factor for passenger cars is 0.8427 and for light trucks is 0.8319. The 7% discount factor for passenger cars is 0.6909 and for light trucks is 0.6755.

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 $1.8 million to $2.2 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 proposed 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 $3.5 million per statistical life. The most recent study relating to the cost of crashes published by NHTSA[2], as well as the most current DOT guidance on valuing fatalities[3], indicate a value consistent with

[2] 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.

[3] "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.

$3.5 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.[4]

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 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 214 effect 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 2002 cost level used in this report. Based on the CPI ALL Items index (179.9/172.2), this would become $3,496,6267. The basis for the benefit-cost analyses will thus be $3.5 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.

[4] For example, Miller, T.R. (2000): "Variations Between Countries in Values of Statistical Life", Journal of Transport Economics and Policy, 34, 169-188.

Table VII-4
Net Benefits with a Value of $3.5M Per Equivalent Life

Oblique Pole	Benefits ($M)		Net Benefit ($M)	
	3%	7%	3%	7%
Combo + 2 sensors	$3,010	$2,457	$1,447	$894
Curtain + 2 sensors	$4,116	$3,360	$1,073	$317
Curtain + 4 sensors	$4,141	$3,378	$561	-$202

VIII. TEST DATA AND ANALYSIS OF MOVING DEFORMABLE BARRIER TEST

This chapter presents test data available to the agency on the various static and dynamic test procedures mandated by the proposed 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.

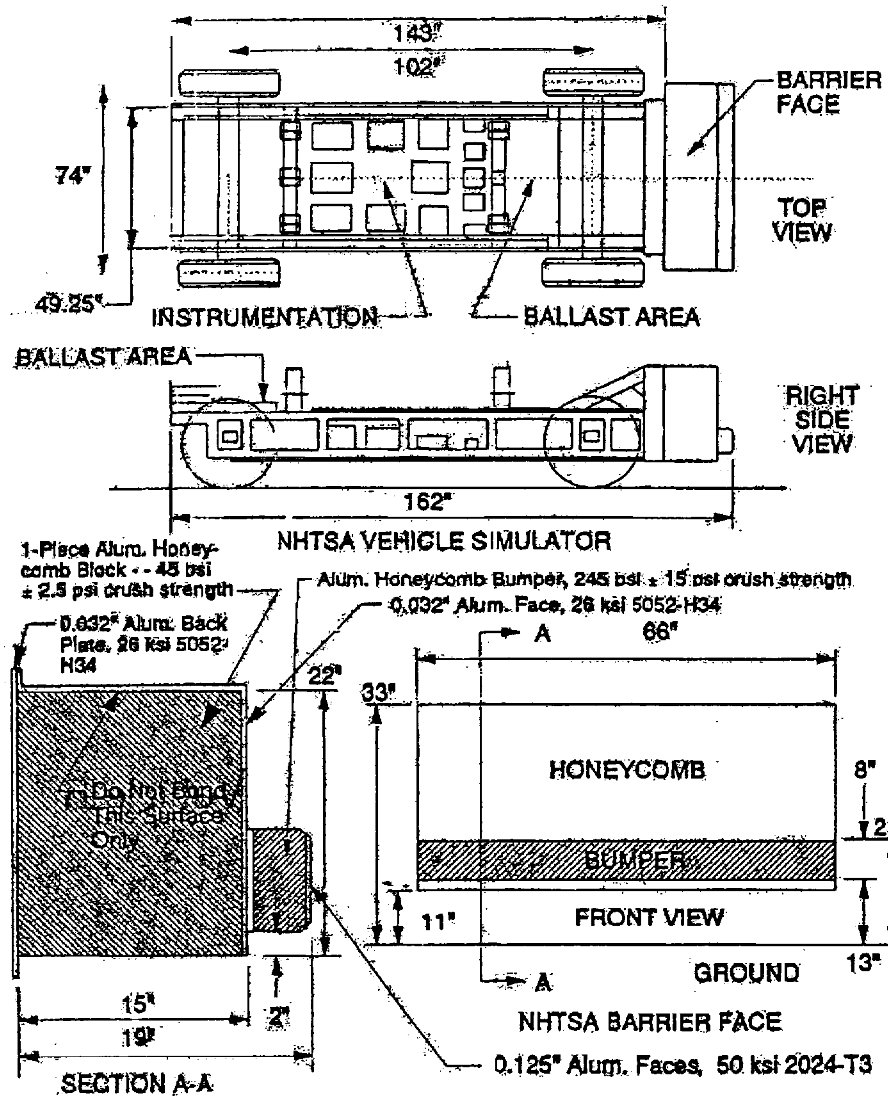


Figure VIII-1. NHTSA Moving Deformable Barrier

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 NPRM would require use of an improved 50th percentile male dummy (either the SID-H3 or 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 proposed for 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. These tests are discussed in detail in the ES-2 Technical Report that has been placed in the docket. Two 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 and -2 for tests of the dummy in the driver and rear passenger positions, respectively.

Table VIII-1
FMVSS No. 214 MDB Test Results
(ES-2re Driver)

Test Vehicle	**Restraint HPS and/or SIAB**	**HIC(d)**	**Rib-Def. (mm)**	**Lower Spine (g)**	**Abd.-Force (N)**	**Pubic-Symph. (N)**
Proposed Limits		1,000	44	82	2,800	6,000
2001 Focus	None	136.7	36.3	59.7	1,648.2	-2,832.9
2002 Impala	None	68.9	45.6	49.3	1,225.2	-1,788.7

Table VIII-2
FMVSS No. 214 MDB Test Results
(ES-2re Rear Passenger)

Test Vehicle	HIC(d)	Rib-Def. (mm)	Lower Spine (g)	Abd.-Force (N)	Pubic-Symph. (N)
Proposed Limits	1,000	44	82	2,800	6,000
2001 Focus	174.2	19.9	58.9	1,121.1	-2,758.6
2002 Impala	186.5	12.4	58.3	4,408.8	-2,784.3

Tables VIII-1 and -2 show that the 2001 Ford Focus would comply with the proposed FMVSS No. 214 MDB test requirements when it is tested with the ES-2re dummy and its associated injury criteria. The Ford Focus is a small 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 indicate that an upgraded MDB test using the ES-2re dummy as its associated injury criteria would be practicable.

The test results also show that the 2002 Chevrolet Impala would not comply with all of the proposed FMVSS No. 214 MDB test requirements because the abdominal force of the rear seat dummy exceeds the 2,800 N limit by a large margin. 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 50^{th} 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. However, this particular modification may reduce the rear seat width by a small amount.

2. Addition of 5^{th} Percentile Female Dummy (SID-IIs) and Injury Criteria

The NPRM also proposes to upgrade the MDB requirements of FMVSS No. 214 by requiring vehicles to comply when tested with the 5^{th} percentile female dummy (SID-IIsFRG). The small stature occupant, relative to the medium stature (1651-1803 mm (65-71 inches) tall) occupant, suffered more head and abdominal injuries and fewer chest injuries. The agency proposes that the criteria proposed for the vehicle-to-pole test must also be met in the MDB test with the SID-IIsFRG.

NHTSA tested the Ford Focus and Chevrolet Impala to FMVSS No. 214's MDB test procedure using the SID-IIsFRG in the driver and rear passenger seating positions. Test results are tabulated below in Tables VIII-3 and -4.

Table VIII-3
FMVSS No. 214 MDB Test Results
(SID-IIs Driver)

Test Vehicle	Restraint HPS and/or SIAB	HIC(d)	Lower Spine (g)
Proposed Limits		1,000	85
2001 Focus	None	181	72
2002 Impala	None	76	52

Table VIII-4
FMVSS No. 214 MDB Test Results
(SID-IIs Rear Passenger)

Test Vehicle	Type of HPS/SIAB	HIC(d)	Lower Spine (g)
Proposed Limits		1,000	85
2001 Focus	None	526	65
2002 Impala	None	153	89

Tables VIII-3 and -4 show that the 2001 Ford Focus would comply with the proposed FMVSS No. 214 MDB test requirements when tested with the SID-IIs FRG dummy and its associated injury criteria. These test results demonstrate that a standard using the proposed SID-IIs FRG dummy and its associated injury criteria would be reasonable and practicable. The 2002 Chevrolet Impala would not comply with the proposed FMVSS No. 214 MDB test requirements, since the lower spine acceleration of the rear seat dummy exceeds the proposed injury limit. As discussed previously, the rear armrest design may be the problem, and a simple remedy is readily available.

3. 50^{th} vs. 5^{th} Dummy Response

Table VIII-1 and VIII-3 show that when the 2001 Ford Focus was tested with the ES-2re and the SID-IIs, it produced a lower-spine acceleration of 59.7g and 72g, respectively. When the 2002 Chevrolet Impala was test with the ES-2re and the SID-IIs, it produced a lower-spine acceleration of 49.3g and 52g, respectively. The lower spine acceleration scores show that the SID-IIs produced higher scores when compared to the ES-2re 50th percent test dummy. The increase ranges from 21% for the Focus to 5% for the Chevrolet Impala.

Benefits

With only two sets of test data, the agency cannot very well feel confident in any estimates that would result from using these test scores and estimating benefits. 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 234 fatalities and 407 AIS 3-5 injuries annually in non-rollover side crashes[1]. 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. However, we do not have sufficient data to quantify these potential benefits. Hopefully additional data will become available, so that an assessment can be made to determine the benefits for the final rule.

Similarly, the agency expects to get benefits from using both the ES-2re and the SID-IIs dummies in the dynamic moving deformable barrier test. In general, the different front seat

[1] For lateral delta-V of 12-25 mph, 1997-2002 CDS, 2001 FARS, 2001 GES. See Chapter V for additional discussion.

seating positions, different seating heights, etc. should require fuller countermeasure coverage than using just one dummy. Both dummies showed potential failures (although with different injury measures of the abdomen and lower spine) of the proposed levels for the rear seat occupants of the Impala. Again, the agency really does not have sufficient data to quantify these potential benefits.

IX. ALTERNATIVES

There were a number of alternative regulatory approaches the agency considered for this rulemaking. These alternatives include:

(a) using the 90 degree pole test in FMVSS No. 201;

(b) using a 90 degree barrier test such as that used by the IIHS; and

(c) applying the pole test to front and rear seats.

Each of these is discussed below.

(a) Alternative 1: The 90 Degree Pole Test In FMVSS No. 201

This is a perpendicular test run with only a 50^{th} 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 5^{th} 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.

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 5^{th} percentile female positioned full forward, would provide benefits as 2,3,9, and 10 o'clock.[1] For the combination head/thorax air bag, we saw where some narrow bags have been produced that would provide benefits in a perpendicular test, but not much more than that. 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 73 percent of the benefit,[2] compared to their benefit with an oblique test requirement.

In the main analysis we had three compliance scenarios, where the 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

[1] There are slightly more fatalities and injuries in 2 and 10 o'clock side impacts than in 3 and 9 o'clock crashes.
[2] The percentage is based on the 89% compliance (i.e., passing) rate of the current head air bags tested with the ES-2re a 50th percentile test dummy. In addition, we assumed that curtain air bags benefit 50% of occupants represented by a 5th percentile test dummy. Thus, Percentage = (passing rate) x [(occupant represented by 50th dummy) + (50% of occupants represented by 5th dummy)]. (89%)x[65% + (0.5)(35%)] = 73%.

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.[3]

[3] 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. For a future analysis, we are considering an examination of air bag sizes and angles and we would have to make assumptions about the distribution of crashes by angles. However, this analysis does point 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.

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	329 fatalities	754 fatalities	758 fatalities
Oblique Angle (wider air bags + possibly more sensors)	357 fatalities	273 fatalities	274 fatalities
Total Benefits for the Proposal	686 fatalities	1,027 fatalities	1,032 fatalities
Perpendicular Angle	422 AIS 3-5 Inj.	733 AIS 3-5 Inj.	761 AIS 3-5 Inj.
Oblique Angle (wider air bags + possibly more sensors)	457 AIS 3-5 Inj.	265 AIS 3-5 Inj.	275 AIS 3-5 Inj.
Total Benefits for the Proposal	879 AIS 3-5 Inj.	998 AIS 3-5 Inj.	1,036 AIS 3-5 Inj.

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.

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	$1,401 Million	$2,909 Million	$2,909 Million
Oblique Angle (wider air bags + possibly more sensors)	$162 Million	$134 Million	$671 Million
Total Costs for the Proposal	$1,563 Million	$3,043 Million	$3,580 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	$ 3.39 Million	$ 3.37 Million	$ 3.34 Million
7% discount rate	$ 4.16 Million	$ 4.13 Million	$ 4.10 Million
Oblique Angle (wider air bags + possibly more sensors)			
3 % discount rate	$ 0.36 Million	$ 0.43 Million	$ 2.14 Million
7% discount rate	$ 0.44 Million	$ 0.53 Million	$ 2.62 Million
Total Costs per Equivalent Life Saved for the Proposal			
3 % discount rate	$ 1.82 Million	$ 2.59 Million	$ 3.03 Million
7% discount rate	$ 2.23 Million	$ 3.17 Million	$ 3.71 Million

(b) Alternative 2: The IIHS Taller MDB test

The agency also considered the merits of proposing the Insurance Institute for Highway Safety (IIHS) test procedure. As noted in section IV(l) of the preamble to the NPRM, vehicle manufacturers have announced that they will begin voluntarily meeting performance criteria for head protection in side impacts when tested to the IIHS test procedure. The IIHS test is a perpendicular (90 degree) moving deformable barrier (MDB) test at 50km/h (31 mph) into the driver side of the vehicle. The MDB is taller (12 inches taller) than NHTSA's MDB and weighs 1,500 kg (3,300 pounds), which is 300 pounds heavier. In the industry's voluntary commitment, a 5^{th} percentile SID-IIs dummy is placed in the driver's seating position (the struck side of the vehicle).

There are differences between the approaches of the voluntary industry commitment and this NPRM as to the performance test and requirements that lead to the installation of side impact air bags. The industry commitment uses a 5th percentile female dummy in the driver's position in a 90-degree MDB test while the NPRM proposes to use the 5th percentile female and a 50th percentile male dummy in both the driver and right outboard passenger position in a 75-degree pole test. The industry commitment limits HIC and head contact with the barrier, while the NPRM proposes limits on HIC and on 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 lb, while the NPRM proposes to apply the pole test to passenger cars and to LTVs with a GVWR of up to 10,000 lb.

As a result of these differences, the agency believes that the NPRM's oblique pole test will result in wider side air bags that are more protective of the heads and other body regions of front seat occupants than the side air bags installed to meet the industry's 90-degree barrier test. The oblique angle of our test would force a wider air bag to cover angular impacts. In a taller vehicle like a medium to full size pickup or SUV, the IIHS barrier (even though it is taller than the NHTSA barrier) may not strike the driver's head, whereas in the pole test the head will be struck unless there is a countermeasure. To date (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.

We assume that manufacturers would use the same countermeasures in either meeting the FMVSS No. 201 pole test or the IIHS barrier test. Thus, we would expect the same costs and benefits would accrue from both (see analysis above). However, if head impact protection were not included for the 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 18 percent. (Total benefits are estimated to be about 80 percent from passenger cars and small light trucks and 20 percent from taller light trucks. Head protection provides about 90 percent of the benefits as opposed to 10 percent for the thorax. Thus, the potential loss in benefits from providing no head protection for the larger light trucks would be 18 percent [.20 * .90]).

(c) 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 a major expense 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.

Table IX-4
Incremental Costs and Benefits for a Rear Seat Test

Front Air Bag System	Combination Air Bag 2 Sensors	Curtain & Thorax Bags 2 Sensors
Rear Air Bag System	Combination Air Bag with 2 Sensors	Thorax Bag with 2 Sensors
Costs[4]	$1,589 Million[5]	$910 Million
Benefits[6]: Fatalities	27	8
Benefits[7]: AIS 3-5	144	52
Equivalent Fatalities (undiscounted)	52	13[8]
Cost per Equivalent Fatality		
3% Discount Rate	$36.6 Million	$125.0 Million
7% Discount Rate	$44.9 Million	$183.0 Million

As Table IX-4 shows, the thorax air bags or combination air bags for the rear seat are not cost effective.

[4] Costs are for the rear air bag system only for the incremental benefits.
[5] We estimated a total of $1,121M for the combo air bags and $468M for the 2 sensors for the rear air bags system.
[6] These are additional benefits that were not covered by the front air bag system.
[7] See Footnote 6 above.
[8] A total of 74 equivalent lives would be saved for occupants in rear seating positions. For these 74 lives, front curtain air bags would save 61 lives and rear thorax bags would save the remaining 13 lives.

After considering the foregoing, the agency decided not to propose to have 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 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.

X. REGULATORY FLEXIBILITY ACT AND UNFUNDED MANDATES REFORM ACT ANALYSIS

A. Regulatory Flexibility Act

The Regulatory Flexibility Act of 1980 (5 U.S.C §601 et seq.) requires agencies to evaluate the potential effects of their proposed and final rules on small business, small organizations and small Government jurisdictions.

5 U.S.C §603 requires agencies to prepare and make available for public comments initial and final regulatory flexibility analysis (RFA) describing the impact of proposed and final rules on small entities. Section 603(b) of the Act specifies the content of a RFA. Each RFA must contain:

1. A description of the reasons why action by the agency is being considered;
2. A succinct statement of the objectives of, and legal basis for a final rule;
3. A description of and, where feasible, an estimate of the number of small entities to which the final rule will apply;
4. 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;
5. An identification, to the extent practicable, of all relevant Federal rules which may duplicate, overlap or conflict with the final rule;

6. Each final regulatory flexibility analysis shall also contain a description of any significant alternatives to the final rule which accomplish the stated objectives of applicable status and which minimize any significant economic impact of the final on small entities.

1. Description of the reason why action by the agency is being considered

NHTSA is considering this action to improve the safety of occupants in front outboard seating positions in side impacts.

The more advanced 50^{th} percentile test dummy equipped with greater instrumentation is available for crash tests. Head and side air bags will be tested to a condition representing a severe crash environment. There are a variety of available technologies for head and side air bag systems. While the availability of air bag related technologies provide more opportunity for consumers to have affordable protection systems, it also means that the agency must ensure that these technologies are effective in protecting consumers. The final rule also extends protection to occupants represented by a 5^{th} percentile female test dummy.

2. Objectives of, and legal basis for, the final rule

NHTSA is requiring these changes 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.

3. Description and estimate of the number of small entities to which the final rule will apply

The final rule would affect motor vehicle manufacturers, second-stage or final stage manufactures, air bag manufacturers, air bag sensor manufacturers, dummy manufacturers, and manufacturers of seating systems. Business entities are now defined as small business 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 second-stage manufacturers, the firm must have less than 500 employees to be classified as a small business.

Small vehicle manufacturers

Currently, there are about 4 small motor vehicle manufacturers in the United States. These manufacturers may have difficulty certifying compliance with tests. Many of these manufacturers have in the past petitioned NHTSA for temporary relief from the air bag rule because of economic hardship. Much of the air bag work for these small vehicle manufacturers is done by air bag suppliers. Typically, air bag suppliers are busy supplying larger companies during the development period, and don't have the design capabilities to handle all of the smaller manufacturers. Thus, the agency has typically allowed small manufacturers that have limited lines to comply at the end of the phase-in period.

Final stage manufacturers and alterers

There are a significant number (several hundred) of second-stage or final-stage manufacturers and alterers that could be impacted by the proposed 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. For the combination thorax/head air bags mounted in the seat, these manufacturers should be able to meet the standard by passing on the compliance by the seat manufacturer. If a higher roof is added, the NPRM proposed to exclude raised-roof vehicles from the oblique pole tests. If a higher roof is not added, and the seats remain in the vehicle, then the original manufacturer's certification should apply. Thus, while there are a significant number of second-stage and final stage manufacturers impacted by the proposed rule, we do not believe the impact will be economically significant. Either a pass-through certification process will apply to these manufacturers or they will be exempt from the standard by the proposal to exempt vehicles with raised roofs.

Air bag manufacturers, air bag sensor manufacturers, dummy manufacturers, and manufacturers of seating systems

The agency does not believe that there are any small air bag manufacturers, and only a few small air bag sensor manufacturers. The proposed rule is expected to have a positive impact on their business.

There are several manufacturers of dummies and/or dummy parts. All of them are considered small businesses. The proposed rule is expected to have a positive impact on these types of small businesses by increasing demand for dummies.

NHTSA knows of approximately 21 suppliers of seating systems, about half of which are small businesses. If seat-mounted combination head/thorax air bags are used to meet the new pole test and upgraded MDB test, the proposed requirements would have a positive impact on these suppliers since the cost of the seats would increase. NHTSA believes that air bag manufacturers would provide the seat suppliers with the engineering expertise necessary to meet the new requirements.

We expect additional business for air bag manufacturers, air bag sensor manufacturers, dummy manufacturers, and manufacturers of seating systems. The proposal would require the use of more air bags, air bag sensors, and anthropomorphic dummies. In addition, we would expect more side air bags to be installed in outboard seating positions. In each case the proposal means positive business for these manufacturers.

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 2002 results in $113 million (110.66/98.1 = 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 100 million annually. Since the proposed rule allow a variety of methods to comply, which have a variety of costs ranging from at least $91 per vehicle for 17.2 million vehicles, it will easily exceed $100 million. The final cost will depend on choices made by the automobile manufacturers.

These effects have been discussed in this Preliminary Regulatory Evaluation. Please see the chapter on Costs.

XI. SENSITIVITY ANALYSES

A. Introduction

This section estimates 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, future safety belt use rates, the effectiveness of countermeasures at different impact speeds, the use of a minimum performance air bag, a variation in the air bag effectiveness against ejections assumed for combination head/thorax air bags, 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) Side impact sensor costs. 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 proposed oblique impact test with two sensors, and still provide adequate 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 $35 to $96. These costs are higher than the agency's estimates of the costs of two satellite frontal impact sensors of about $25. In the PEA, the

agency assumes that the costs of two side impact sensors will decrease to an average cost of $35, and provides cost estimates assuming either two or four sensors will be needed per vehicle. If the $96 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 $96 for 2 Sensors

Air Bag System	Total Cost (Millions)*	Average Cost Per Vehicle
Combo	$2,305.35	$133.82
Curtain + Thorax with 2 sensors	$3,785.79	$219.76
Curtain + Thorax with 4 sensors	$5,250.87	$304.81

* Present value

With the $96 sensor cost, the cost per equivalent life saved would increase to $3.3 million for the combo, $3.9 million for the curtain with 2-sensors and $5.2 million for the curtain with 4 sensors[1].

(2) Increase in safety belt use. The analysis examined air bag benefits at an increased observed belt usage rate of 79% in 2003, a rate two percentage points greater than the 2002 rate. If the annual two percentage point increase in safety belt use continues for the next five years to 87% in 2007, 68 additional fatal ejections would be prevented in 2008[2]. As discussed in Chapter V, to

[1] At 7% discount, with the $35 sensor cost, we estimated $2.2(M) for the combo, $3.2(M) for the curtain with 2 sensors, and $3.7(M) for the curtain + 4 sensors.

[2] Reduction in Head & Facial Injury Target Population due to Change in Safety Belt Usage Rate
State Observed Safety Belt Usage Rate

Year	Usage Rate	
1997	0.669	
1998	0.687	
1999	0.701	
2000	0.727	
2001	0.75	
2002	0.77	
2003	0.79	
2004	0.81	(2004 - 2008 belt usage rates were estimated .)
2005	0.83	
2006	0.85	
2007	0.87	Average Usage Rate for 97 - 07: 0.768545

estimate the benefits of side air bags at different belt use rates, the baseline target population must be adjusted to reflect the impact of increased belt use. Thus, higher belt use would reduce the target population by 68 resulting in a revised target population of 332 head and facial injuries from complete occupant ejection in side crashes. Since we assumed that combo air bags are not effective in preventing ejection, the reduction would not affect the estimated benefits for this analysis. However, the reduction would reduce the fatal benefits from 1,027 to 1,000 for the curtain + thorax air with 2 sensors and from 1,032 to 1,005 for the curtain + thorax with 4 sensors.

(3) The effectiveness of the countermeasures at different impact speeds. The agency has tested both the combination chest/head air bag and the separate window curtains with thorax air bags at 18 mph perpendicular and 20 mph oblique poles tests. However, the agency has very limited knowledge on bag performance at higher impact speeds. Thus, the agency does not know how the effectiveness of the countermeasures decreases as test speed increases. The devices are very effective in the 20 mph pole test, which produces a vehicle delta V of 19 mph[3]. In the PEA, we

---

2008 0.89

(I) Adjustment for Fatalities

Current Fatalities: 400

UPFC:	0.615328	(UPFC corresponding the average usage rate of 0.768545)
Safety Belt Effectiveness:	0.6734	
Potential Fatality:	683.0159	
Current Saved by Belt:	283.0159	
UPFC:	0.763643	(UPFC corresponding the new belt usage rate of 0.89)
Safety Belt Effectiveness:	0.6734	
Potential Fatality:	683.0159	
Saved by Higher Rate:	351.2323	

Net Prevented at Higher Rate: 68.21641

[3] 20.0 mph times the cosine of 15 degrees is 19.3 mph.

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. According to the target population, a total of 2,495 fatalities[4] occurred in side crashes for a vehicle delta-V range of 12-25 mph, annually. The benefit analysis shows that if all vehicles were equipped with the combination system, a total of 686 additional lives would be saved. Thus, the combination system would be 27.49% effective[5] against fatalities. If the effectiveness decreases gradually[6] from 27.49% at a vehicle delta-V of 20 mph to 0% at a vehicle delta-V of 30mph[7], the combination system would save 735 lives[8].

(4) The benefit estimation was based on an average performance of current air bags tested[9], 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

[4] Includes only head, chest, abdominal and pelvic injuries, adjusted with the expected 201 benefits and also the increase in safety belt use rate.
[5] The effectiveness is for the target population considered.
[6] For a vehicle delta-V range of 20 mph to 30 mph, we assumed a curvilinear decrease in effectiveness from 20 mph to 30 mph with the following equation: Effectiveness $(\Delta V) = -0.0036(\Delta V)^2+0.1522(\Delta V)-1.331$, and 0% at 30mph.
[7] We assumed that fatalities are evenly distributed for a vehicle delta-V range of 26 – 30mph.
[8] The corresponding effectiveness with respect to delta-V is shown below:

Delta-V	Effectiveness	Target Population	Saved
12-20	27.49%	1447	398
21	27.76%	202	56
22	27.50%	346	95
23	26.52%	40	11
24	24.82%	346	86
25	22.40%	114	26
26	19.26%	125	24
27	15.40%	125	19
28	10.82%	125	13
29	5.52%	125	7
30	0.00%	125	0

Delta-V	Cumulative Saved
12-20	398
12-21	454
12-22	549
12-23	560
12-24	646
12-25	671
12-26	695
12-27	714
12-28	728
12-29	735
12-30	735

[9] 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.

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 proposed requirements produced lower injury scores when compared to the proposed injury requirements. Since the proposed injury 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. To determine potential impacts of the hypothetical minimum performance air bags, we analyzed the minimum benefits for each body region, as shown below:

For head injuries, 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 proposed standard at 1,000 HIC would also be equally effective as ones designed to meet the requirement, for example, at 500 HIC[10] in preventing fatal head injuries. However, for nonfatal serious head injuries (AIS 3 - 5), the minimum performance head air bag would reduce the AIS 3, AIS 4 and AIS 5 benefits by 170, 81 and 15, respectively, when compared with the production head air bags tested in the pole test[11]. Therefore, when the

[10] Without head air bags, HIC ranges from 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.

[11] For the derivation, only the head-to-pole and head-to-striking vehicle cases were considered. The minimum performance air bag would reduce the benefits by 48 equivalent lives, as shown below:

Vehicle-to-pole side crashes

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatal
Production bags	-227	127	-17	23	77	261
Minimum Performance bags	-152	102	-81	-6	71	260
Difference	75	-25	-64	-29	-6	-1

Vehicle-to-vehicle side cashes

	AIS 1	AIS 2	AIS 3	AIS 4	AIS 5	Fatal
Production air bags	-1189	857	280	372	250	504

performance is reduced to just meet the minimum performance requirement, it would not have any significant impacts on the head benefit estimation.

For thorax injuries, the target population was divided into two groups: population represented by a 50th percentile male test dummy and population represented by a 5th percentile female test dummy. For occupants represented by a 50th percentile male test dummy, a total of four vehicles were tested with the 214 seating procedure in the proposed pole test: 1999 Volvo S80, 2000 Saab, 2004 Honda Accord and 2004 Camry[12]. Among these vehicles, the Honda Accord with a chest deflection of 30.7 mm was the only vehicle that met the proposed chest deflection of 42 mm. The expected chest benefits with respect to chest deflection are shown in Figure XI-1.

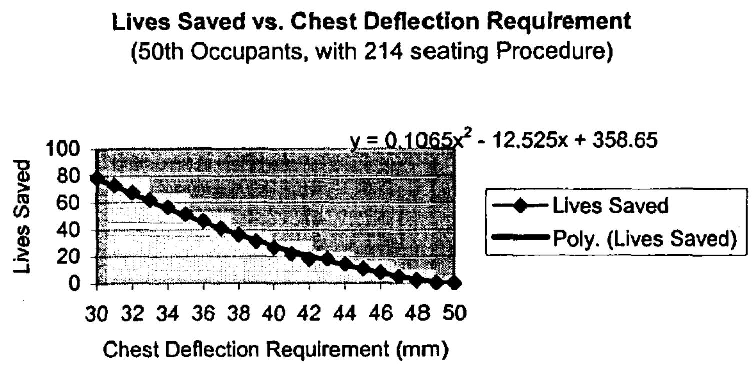


Figure XI-1. Lives Saved vs. Chest Deflection Requirement for 50th Occupants

Minimum Performance bags	-1054	812	165	320	241	503
Difference	135	-45	-106	-52	-9	-1

[12] The 1999 Volvo S80 was equipped with Curtain + Thorax and has a deflection of 48.6mm, the 2000 Saab was equipped with Combo and has a deflection of 49.4mm, the 2004 Honda Accord was equipped with Curtain + Thorax and has a deflection of 30.7mm, and the 2004 Toyota Camry was equipped with Curtain + Thorax and has a deflection of 43.4mm. Since there was no "true" baseline (i.e., measurement made without deployed air bag.), the "failed" scores were used as baseline scores.

Figure XI-1 shows that about 75 lives would be saved with thorax air bags if all deployed thorax air bags result in a chest deflection of 30.7 mm in the pole test. On the other hand, if all air bags were designed to just meet the proposed deflection of 42 mm, about 20 lives would be saved by these "minimum performance" air bags.

For occupants represented by a 5th percentile female test dummy, the expected chest benefits based on the lower spine acceleration are shown in Figure XI-2.

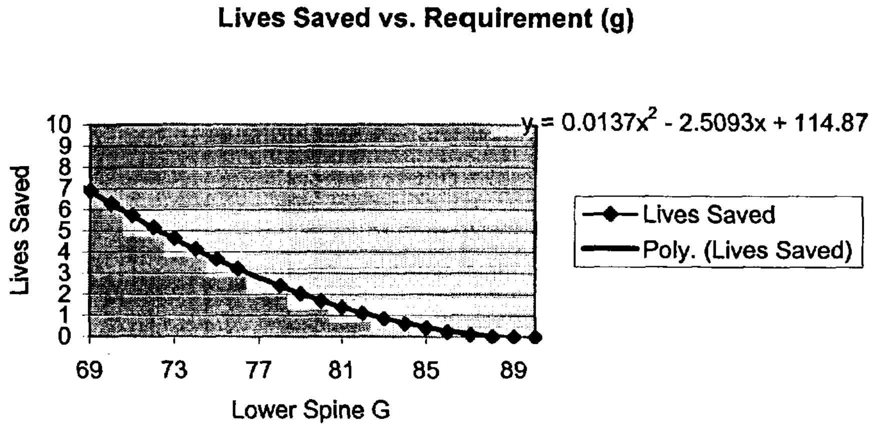


Figure XI-2. Lives Saved vs. Chest Requirement for 5th percentile Occupants

As shown in Figure XI-2, the current production thorax air bags[13] would save about 7 lives with an average lower spine acceleration of 69g measured with the 5th female test dummy, SID-IIs. On the other hand, if all thorax air bags were designed to just meet the proposed 82g lower spine requirement, air bags would save about one fatality[14].

[13] The air bags tested with the SID-IIs in the pole test.
[14] As shown in Chapter V, Dr. Kahane found that current thorax air bags might not be effective in side crashes based on the limited real world crash data.

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 proposed 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.

(5) For the benefit estimation, we assumed that combo air bags are not effective in preventing occupants from ejection. The assumption is based on the oblique pole test results where some combo air bags failed to retain the head during the impact. To comply with the proposed oblique pole requirements, vehicle manufacturers may install wider combo air bags. Unlike the narrow combo air bags we tested, these wider combo air bags may be effective in preventing occupants from ejection in certain lateral or near lateral non-rollover side crashes.

Based on our 2001 FARS target population, about 43% of all injuries occurred in 3 and 9 o'clock impact directions for a lateral vehicle delta-V range of 12 – 25 mph. In addition, it shows that 30% of the head and facial fatalities were from complete ejection crashes. The percentages show that 13%[15] of the complete ejection cases that we considered in the analysis would be from the 3 and 9 o'clock impacts. If we assume that the wider combo air bags are effective in reducing

[15] 43%*30% = 13%

complete ejection in 3 and 9 o'clock lateral crashes, a total of 42 additional lives[16] would be saved with the wider combo air bags.

(6) 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 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 2001 FARS target population of 3,070 near side front outboard and 141 near side rear outboard occupants fatalities (a total of 3,211 fatalities), we estimated combo air bags are 21% effective[17], likewise, curtain+ thorax air bags are 32% effective in preventing fatality. In other words, if all vehicles were equipped with curtain+ thorax air bags, a total of 1,027 lives would be saved (3,211 x 32% = 1,027). According to the 2003 air bag distribution, as shown in Table V-102, there are 1,180,414 curtain+thorax air bags and 1,287,874 combo air bags. If we assume the distribution ratio (i.e., curtain+thorax/combo air = 1,180,414/1,287,874) remains unchanged when installed in the full fleet of vehicles, a total of additional 849 lives would be saved[18], annually.

---

[16] We estimated that approximately 322 lives (306 front and 16 rear occupants) would be saved by curtain air bags. With the wider combo air bags, 42 additional lives would be saved (322* 13% = 42). Thus, the estimated lives saved by the combo would increase from 686 to 724 lives.

[17] According to the benefit analysis, a total of 686 additional lives would be saved with the combo. Thus, the overall effectiveness on fatality would be: 686/3,211 = 21%. Likewise, the curtain + 2 sensors would be: 1,027/3,211 = 32%

[18] curtain+thorax : combo = 1,180,414 : 1,287,874 resulting in 47.82% curtain and 52.18% combo, assuming all vehicles are equipped with one or the other system. The expected 849 additional lives saved are expressed by the following equation: (3,070 + 141)[(47.82%)(31.98% effectiveness) + (52.18%)(21.36% effectiveness)] = 849.

(7) In Chapter VII, we used a value of $3.5 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) literature[19]. 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-2.

Table XI-2
Net Benefits with a Value of $5.5M Per Equivalent Life

Countermeasure	Benefits ($M)		Net Benefit ($M)	
	3%	7%	3%	7%
Combo + 2 sensors	$4,730	$3,861	$3,167	$2,298
Curtain + 2 sensors	$6,468	$5,280	$3,425	$2,237
Curtain + 4 sensors	$6,507	$5,308	$2,927	$1,728

C. Summary

The study shows that the overall cost of the combination system[20] would increase from $1,563 million to $2,305 million when the highest estimated sensor cost is used. In addition, it shows that when manufacturers design the bag system to just meet the minimum performance requirement, it would result in a 9 percent reduction in fatality benefit. With the $96 sensor cost, the system would produce a cost per equivalent fatality of no more than $3.5 million. Even with the $96 sensor cost and the minimum performance combined, the system would produce a cost

[19] 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.

[20] In Chapter VI, we determined that the combo would be the least expensive air bag system among the three systems examined.

per equivalent fatality of no more than $5.5 million [21]. Although the $96 sensor and the minimum performance would be the most significant factors that influence the benefits estimated in Chapter V, there are other factors that would affect the estimate, such as safety belt use rate and percent air bag distribution. Some of these factors would increase the estimated benefits. For example, the study shows that if the combination system is effective up to 29 mph, with a curvilinear decrease in effectiveness from 20 mph to 30 mph, it would result in an additional 49 fatal benefits. In addition, the wider combo air bags could be effective in reducing complete occupant ejection in 3 and 9 o'clock lateral crashes. If they are indeed effective in these crashes, a total of 42 additional lives would be saved with the wider combination air bags. The results of all sensitivity analyses for the combination system are presented in Table XI-3[22].

Table XI-3
Summary of Sensitivity Analyses for Combination Air Bag System

Sensitivity factor	Equivalent lives saved		Total Cost (in millions)	Cost per equivalent life saved (in $M)		Total Benefits (w/ 7% discount)		Net Benefits (w/ 7% discount)	
	3% discount	7% discount		3% discount	7% discount	With $3.5M	With $5.5M	With $3.5M	With $5.5M
Sensor	860	702	$2,305	$2.68	$3.28	$2,457	$3,861	$152	$1,556
Impact Speed	872	711	$1,563	$1.79	$2.20	$2,489	$3,912	$926	$2,349
Minimum Performance	748	611	$1,563	$2.09	$2.56	$2,137	$3,358	$574	$1,795
Ejection	897	732	$1,563	$1.74	$2.14	$2,562	$4,026	$999	$2,463

[21] We assumed that the 9% is applicable to the 702 equivalent fatalities discounted at 7% for the combination system [702x(1-0.09) = 638 equivalent lives saved]. With the $2,305M cost and the 638 equivalent lives saved, the cost per equivalent life saved would be $3.6M, as shown: ($2,305M/638 = $3.6M)

[22] As discussed, combo air bags would not be effective in preventing complete occupant ejection in side crashes. For the curtain+thorax with 2 sensors, the cost/equivalent life and net benefits are shown below:

Sensitivity factor	Equivalent lives saved		Total Cost (in millions)	Cost per equivalent life saved (in $M)		Total Benefits (w/ 7% discount)		Net Benefits (w/ 7% discount)	
	3% discount	7% discount		3% discount	7% discount	With $3.5M	With $5.5M	With $3.5M	With $5.5M
High. rate	1,153	941	$3,043	$2.64	$3.24	$3,294	$5,176	$251	$2,133
Baseline	1,176	960	$3,043	$2.59	$3.17	$3,360	$5,280	$317	$2,237

The sensitivity study examined several important alternatives to the assumptions used in the cost and benefit analysis. In summary, the examination shows that the analysis is relatively insensitive to the alternative assumptions analyzed, even with the most favorable and unfavorable assumptions examined.

XII. PROBABILISTIC UNCERTAINTY ANALYSIS

This chapter identifies and quantifies the major uncertainties in the cost-effectiveness and benefit-cost analyses. The purpose of the uncertainty analysis is to identify the areas of unknowns in the economic assessment and describe them with degrees of probability or plausibility. This facilitates a more informed decision-making process.

The analysis starts with mathematical models that imitate the actual processes in deriving cost-effectiveness and net benefits, as shown in previous chapters. Each uncertainty variable (e.g., cost of technology) in the models represents a factor that would potentially alter the model outcomes if its value were changed. The impacts of some uncertainty variables are more important than others. Thus, the next step of the analysis is to identify variables that have an appreciable degree of uncertainty and significantly impact the estimated outcomes. These variables are called significant factors. For each of these significant factors, its degree of uncertainty (also called variation) is described by an appropriate probability distribution function. These probability functions are established based on the available data and professional judgments. The final step is to simulate the model results as probability distribution rather than single-value estimates.

Unlike the earlier point estimates of benefits, the uncertainty analysis is a probabilistic approach using the Monte Carlo statistical simulation technique[1]. The simulation process is run repeatedly. Each complete run is a trial. For each trial, the simulation first

[1] Any statistics books describing the Monte Carlo simulation theory are good references for understanding the technique.

randomly selects a value for each of the significant 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 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 simulation, 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, credibility). The degree of certainty provides the decision-maker an additional piece of important information to evaluate the forecast results.

Simulation Models

Mathematical models were built to imitate the process used in deriving cost-effectiveness and net benefits (benefit-cost analysis) as developed in previous chapters. The cost-effectiveness measure is cost per fatality equivalent avoided. In other words, at a given discount rate, the cost-effectiveness is the total costs divided by the total fatal equivalents avoided at that discount level. The cost-effectiveness model has the following format with dummy variable $P_{k0} = 0$:

$$CE_r = \frac{\text{total costs}}{\text{total fatal equivalents at the } r^{th} \text{ level of discount rate}}$$

$$= \frac{C*V}{d_r*(1-a)*[\sum_{k=1}^{n} \sum_{i=1}^{6} f_i*(P_{ki}*e_{ki} - \sum_{j=1}^{i-1} P_{ki}*e_{ki}*c_{kij})]}$$

Where CE_r = cost-effectiveness with r = 1: no discount, r = 2: 3% discount rate,

r = 3: 7% discount rate

C = cost per vehicle

V = total number of vehicles

d_r = accumulative lifetime discount factor associated with the r^{th} level of discount rate

a = adjustment factor for current side air bag benefits

f_i = injury-to-fatality equivalence ratios

P_{ki} = target population for each body region k, fatalities and MAIS 5 to 1 injuries for i = 1…6

e_{ki} = effectiveness of side air bags against corresponding target population P_{ki}

c_{kij} = injury redistribution factors for injury level i to level j, for body region k

The benefit-cost analysis calculates the net benefits of the proposal, i.e., the difference between the total dollar value that would be saved from reducing fatalities and injuries and the total costs of the rule. Benefits (fatalities and injuries reduced) were already expressed as fatal equivalents for the cost-effectiveness model. Thus, the net benefit model is just one step beyond from the cost-effectiveness model, using an additional variable – cost per fatality (M). The net benefit format is:

NB_r = total dollar saved at the r^{th} level discount rate – total cost

= cost per fatality * fatal equivalents at the r^{th} level discount rate – total cost

$$= M * d_r * (1-a) * [\sum_{k=1}^{n} \sum_{i=1}^{6} f_i * (P_{ki} * e_{ki} - \sum_{j=1}^{i-1} P_{ki} * e_{ki} * c_{kij})] - C * V$$

Where NB_r = net benefits associated with the r^{th} level of discount rate

M = cost per fatality

Significant Factors

The analysis identifies three significant uncertain factors for the cost-effectiveness model: target population (P_{ki}), effectiveness (e_{ki}), and costs (C). The cost per fatality (M) is an additional significant factor for the net benefit model.

Target population, P_{ki}, is obviously important to benefit estimates because it defines the population at risk without the rule. The major uncertainties in this factor arise from, but are not limited to, demographic projections, driver/occupant behavioral changes (e.g., shifts in safety belt use), increased roadway traveling, 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. Overall, no significant trend was found about these characteristics. The next section "Quantifying Significant and Constant Factors" discusses this trend analysis in detail.

Effectiveness of countermeasures, e_{ki}, is by far the parameter with the greatest uncertainty. The sources of its uncertainties 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.

The cost estimate is also 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 economies from production volume).

These three factors by no means comprise a comprehensive list of significant factors. For example, the injury-to-fatality fatal equivalence ratios (f_i) affect the total fatal equivalent estimates. These ratios reflect the relative economic impact of injury compared to fatality based on their estimated comprehensive unit costs. They were derived based on the most current 2002 crash cost assessment[2]. The crash cost assessment itself is a complex analysis with an associated degree of uncertainty. At this time, these uncertainties are unknowns. Thus, the variation in these ratios is unknown and this analysis treats the ratios as constants. Similar arguments also apply to the injury redistribution factors (c_{kij}) and discount factors (d_r). Compared to the head benefits, the estimated chest benefits are

[2] The Economic Impact of Motor Vehicle Crashes 2000, DOT HS 809 446, May 2002

relatively small and have less impact on the overall stability of the benefit estimates. For this reason, chest benefits are treated as constants. The remaining factors include: the total number of vehicles (V) and the adjustment factor for current side air bag benefits (a), both considered to have less impact on the simulated results. These two factors are treated as constants as well.

After analyzing the factors, the above cost-effectiveness and net benefit models can be simplified as follows:

$$CE_r = \frac{C*V}{d_r*(1-a)*[\sum_{i=1}^{6} f_i*(P_i*e_i - \sum_{j=1}^{i-1} P_i*e_i*c_{ij}) + T_i]} \text{ and}$$

$$NB_r = M*d_r*(1-a)*[\sum_{i=1}^{6} f_i*(P_i*e_i - \sum_{j=1}^{i-1} P_i*e_i*c_{ij}) + T_i] - C*V$$

Where P_i = target population of head injuries and fatalities

e_i = effectiveness of side air bags against P_i

c_{ij} = injury redistribution factors for head injuries

T_i = net chest benefits (after injury redistribution process)

Quantifying Significant and Constant Factors

As mentioned previously, P_i (target head population), e_i (effectiveness), C (cost per vehicle), and cost per fatality (M) are factors with appreciable uncertainties that will be analyzed. Their input values to the certainty bound calculation are based on their probability distributions. The remaining factors are treated as constants.

Significant Factors

The target population includes fatalities and MAIS 1-5 head injuries (P_is). Target head fatalities were derived from two crash database: FARS and CDS. FARS data were used in calculations based on Kahane's analysis (see pages V-78 to V-80) [3], which addresses the overall fatality effectiveness rate. CDS data were used in the main model, which focused on specific head and chest injuries. For FARS-derived fatalities, we examined the 1998 -2002 historic fatalities to ascertain the variability of the fatal target population due to demographic, behavioral changes, and other factors discussed in the previous section. Based on 1998 to 2002 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. Thus, the analysis treats the 2001 FARS-derived fatalities as a constant - 5,225.

For CDS-derived fatalities, the analysis considers the associated survey errors and treats fatalities as normally distributed. Similarly, MAIS 1-5 target head injuries were derived from CDS and their probabilities also were treated as normal distributions. About 68 percent of the estimated target population is within one standard error (SE) of the mean survey population. Thus the survey mean population and corresponding standard errors

[3] In response to IIHS analysis "Efficacy of Side Airbags in Reducing Driver Deaths in Driver-Side Collisions" by Elisa R. Braver and Sergey Y. Kyrychenko, August 2003.

were used for establishing the normal distribution for the size of the target population. The standard errors were derived using the formula[4]:

$$SE = e^{3.65254+0.04723\ln(x)^2}, \; x = \text{estimated target head injuries.}$$

Table XII-1 summarizes the mean and standard errors for three different compliance options[5].

Note that the CDS-derived estimates are the averages of 1997-2001. Using multiple years of data generally provides a more stable estimate but it also smoothes out the trends in demographic and behavior changes. In addition, the variations among five-year-moving averages (i.e., 1996-2000; 1995-1999; etc) are within the survey errors, thus, the demographic and behavior changes are not further considered.

Table XII-1
Means and Standard Errors for Normal Distributions
For Target Head Fatalities and Injuries
By Three Compliance Options*

Injury Severity	Option 1		Option 2		Option 3	
	Mean	SE	Mean	SE	Mean	SE
Fatalities from CDS (P_1)	683	288	1,084	387	1,091	389
MAIS 5 (P_2)	358	198	377	203	377	203
MAIS 4 (P_3)	297	178	423	217	423	217
MAIS 3 (P_4)	132	119	175	136	246	161
MAIS 2 (P_5)	2,712	738	3,015	799	3,015	799
MAIS 1 (P_6)	10,403	2,194	11,542	2,404	11,603	2,415

* 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.

[4] 1995-1997 National Automotive Sampling System, Crashworthiness Data System, DOT HS 809 203, February 2001

[5] 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. See Chapter VI for detailed discussions.

Effectiveness of side air bags against fatalities, like the fatal target population described above, has two estimates. One is from Kahane's study. Kahane estimated that the mean effectiveness of side air bags against fatalities is 23 percent with a standard deviation of 8 percent. The effectiveness is normally distributed. The 23 percent effectiveness for all side air bags is against all target fatalities, regardless of injured body regions. Thus, its corresponding target population is 5,225. No compliance options, i.e., technology based implementations, are available for this assessment.

The other effectiveness estimate is derived from laboratory crash test data and empirical injury curves. This estimate is different for different injured body regions. As stated earlier, head injuries are the focus of this uncertainty analysis and therefore only the effectiveness rates against head injuries are estimated here. The laboratory crash test HIC results were normally distributed around their means and standard deviations. Table XII-2 lists these means and standard deviations for the 50th percentile males. Pole test results were used to calculate the effectiveness rates for vehicle-to-vehicle crashes. Head form tests were used to calculate effectiveness for head-to-interior crashes. Note that the agency has two vehicle test data points for the 5th percentile female dummy. One is the comparison data point: data from a vehicle equipped with side air bags that passed the proposal. The other is the control data point: data from a vehicle without the side air bags[6]. With only one-paired crash test data point (comparison – with bags, control – no bags), the analysis is unable to derive the expected variability for the 5th percentile females. To compensate for this, the test results for the 50th percentile males were applied to the small stature occupants represented by the 5th percentile female dummy.

[6] See Table V-12. With air bags: HIC=512; Without side air bags: HIC=14,362

This decision was also based on the test results showing that the HIC performance of 5th and 50th were similar.

Table XII-2
Means and Standard Deviations for HIC Vehicle Crash Test Results
50th Percentile Male Dummy*

Tests	Mean	Standard Deviation
Pole Tests without Air Bags At 20 mph (32 kmph)	14,242	1,969
Pole Tests with Air Bags At 20 mph (32 kmph)	502	194
Head Form Test**	786	113

* results also were applied to the 5th percentile female dummy
**from FMVSS No. 201 feasibility study.

For this analysis, the lognormal curves for head injury risks were used to estimate variation in effectiveness because the curves were derived through a more rigorous statistical process with well-established confidence bounds. Chapter III details these injury curves.

The generation of probability distributions for the effectiveness rates is built into the modeling process. Crystal Ball automatically generates the probability distribution for the effectiveness rates based on the crash data distribution and its corresponding probability risks ranging within the 95 percent confidence bounds of the injury curves. Figures 1 – 5 depict the probability distribution for effectiveness against fatalities and MAIS 2-5 injuries. The effectiveness against MAIS 1 is 0. The corresponding target populations for this set of effectiveness rates are those derived from CDS. Note that the "Frequency" scale shown on the right side of the figures indicates the number of trials that the Monte Carlo simulation uses to derive that specific effectiveness.

The high effectiveness rates were 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.

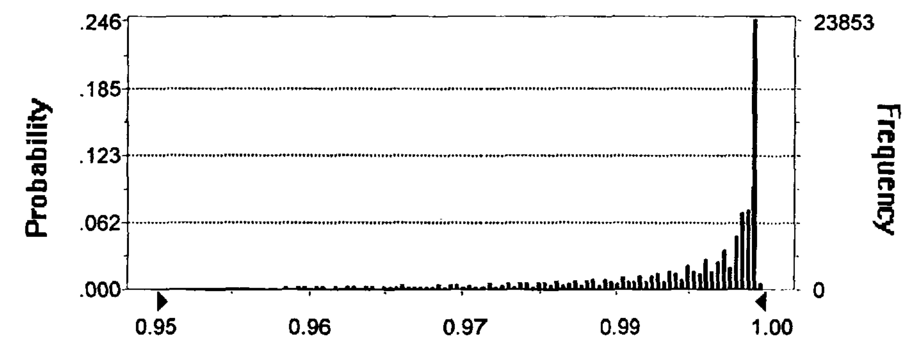


Figure 1
Probability Distribution of Effectiveness of Side Air Bags Against Fatalities

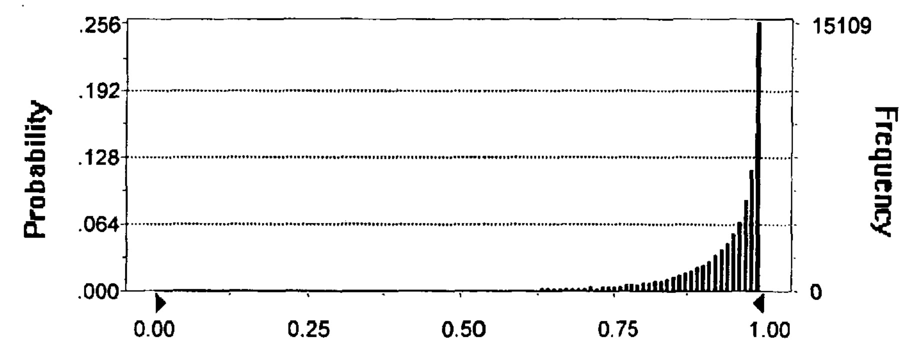


Figure 2
Probability Distribution of Effectiveness of Side Air Bags Against MAIS 5 Injuries

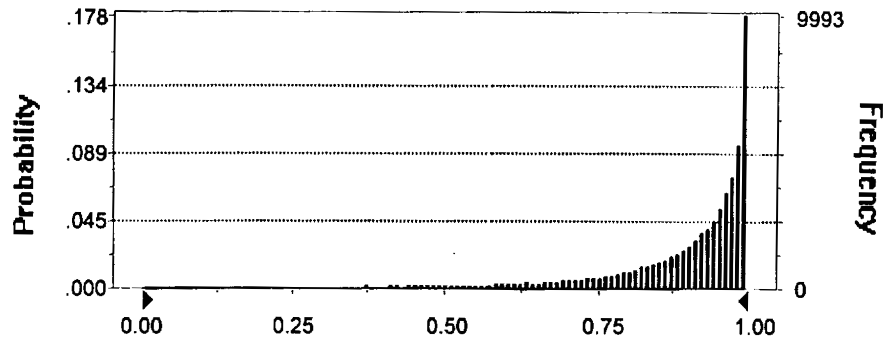


Figure 3
Probability Distribution of Effectiveness of Side Air Bags Against MAIS 4 Injuries

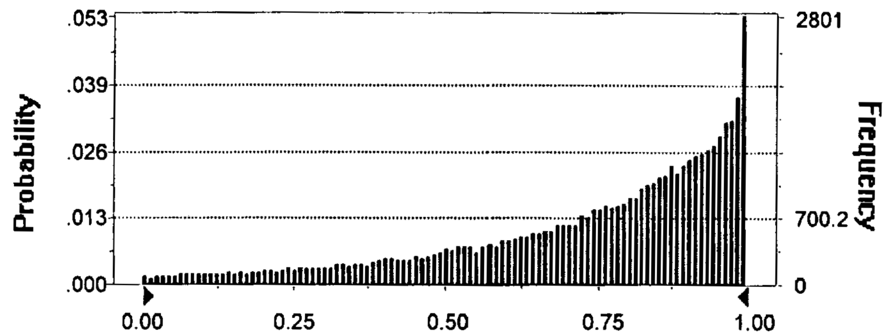


Figure 4
Probability Distribution of Effectiveness of Side Air Bags Against MAIS 3 Injuries

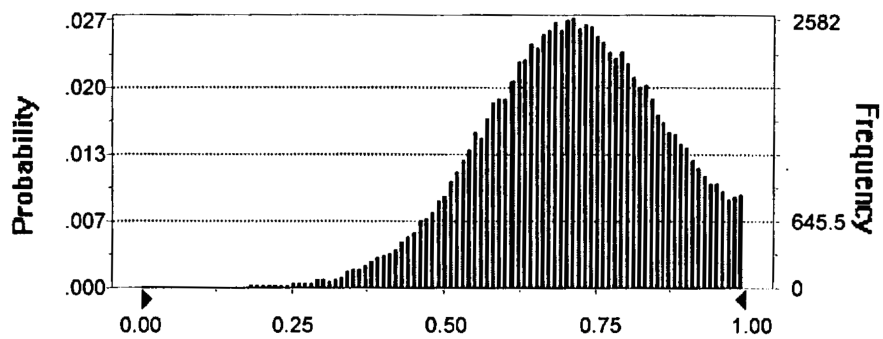


Figure 5
Probability Distribution of Effectiveness of Side Air Bags Against MAIS 2 Injuries

As for the cost per vehicle (C), the analysis assumes it is uniformly distributed. According to professional judgments of NHTSA cost analysts and contractors, the cost will fall within 10 percent of the point estimate shown in Table XII-3. The uniform distribution for C would be established by two parameters: maximum (C_{max}) and minimum (C_{min}) costs, i.e.,

$$C(x) = \frac{1}{C_{Max} - C_{Min}}, C_{min} \leq x \leq C_{max}$$
$$= 0, \text{otherwise}$$

C_{max} and C_{min} varied depending on the implementation options. Table XII-3 lists these costs for the three options.

Table XII-3
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
Maximum Cost (C_{max})	$100.1	$194.70	$228.80
Minimum Cost (C_{min})	$81.9	$159.30	$187.20
The Most Likely Cost (point estimate)	$91.0	$177.00	$208.00

The net benefit model has one additional variable M (cost per fatality). 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[7]. 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. The

[7] 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.

characteristics of the remaining factors are the same as those described in the cost-effectiveness model.

Constant Factors

Other variables such as cumulative lifetime discount factors (d_r), benefit adjustment factors for current side air bags (a), injury-to-fatality equivalence ratios (f_i), injury redistribution factors (c_{ij}), and chest benefits (T_i) are treated as constants. The theories and methodologies used to derive these constants are detailed in the earlier chapters describing benefits and cost-effectiveness and thus are not repeated here. Tables XII-4 to XII-5 summarize all these constants. Note that the injury redistribution factors listed here are only for the head injuries. The net chest benefits were treated as constants in the simulation models and thus no redistribution process is required for the chest injuries.

Table XII-4
Constant Factors for the Cost-Effectiveness Model

Constant Factors	No Discount	3% Discount	7% discount
Cumulative Lifetime Discount Factor (d_r)	1	0.8373	0.6832
Adjustment Factor for Current Side Air Bag Benefits (a)	10.2	10.2	10.2

Table XII- 5
Fatal Equivalent Ratios, Injury Redistribution Factors, and Net Chest Benefits

		Fatality	MAIS 5	MAIS 4	MAIS 3	MAIS 2	MAIS 1
Injury-To-Fatality Equivalence Ratios (f_i)*		1.0000	0.7124	0.2153	0.0916	0.0458	0.0031
Injury Redistribution Factors For Head Injuries* (c_{ij})	Fatality	0.0000	0.0026	0.0036	0.0393	0.1431	0.6156
	MAIS 5		0.0000	0.0036	0.0394	0.1435	0.6172
	MAIS 4			0.0000	0.0395	0.1440	0.6194
	MAIS 3				0.0000	0.1494	0.6425
	MAIS 2					0.0000	0.7587
Net Chest Benefits Before Discounting** (T_i)		82	2	37	18	-10	-1

* same for each discount level; ** after the injury redistribution process

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 the 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 had certainty bounds. This uncertainty analysis conducted a total of 100,000 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 100,000. These criteria were chosen to ensure the simulation errors ($\approx \frac{1}{100{,}000}$) would be very close to 0. Therefore, the results would truly reflect the probabilistic nature of the uncertainty factors.

Since the analysis used two different sources to derive fatalities and its effectiveness rate, for comparison purposes, the following "Fatality Benefits" section discusses the fatality benefits from these two sets of fatality and effectiveness values. The "Net Benefits" section summarizes the complete simulation outcomes based on the CDS derived target population and crash tests/injury curve derived effectiveness rates.

Fatality Benefits

As described previously, target fatalities and their corresponding effectiveness were derived using two different sources and methodologies. This section compares the results derived from these two sets of values. Since the FARS-centered assessment does not include injuries, only the fatality benefits can be compared. The fatality benefits can be derived from this simplified model (bottom part of CE model):

$$B = d_r * (1 - a) * P_1 * e_1$$

For the FARS-centered assessment, the target population is a constant, i.e., $P_1 = 5{,}225$. The corresponding effectiveness (e_1) is normally distributed with a mean of 23 percent and one standard deviation of 8 percent. These FARS-centered benefits are called FARS-centered model results.

After about 100,000 trials, this model forecasts that the proposal would save an average of 1,073 lives. Furthermore, the proposed rule would save 408 – 1,688 lives with 90 percent certainty. At a 3 percent discount rate, the average present value of the stream of lives saved over the lifetime of those vehicles is 899 lives. With this discount rate, the present value of the lives saved would be 402 – 1,405 with 90 percent certainty. At a 7 percent discount rate, the average present value of the stream of lives saved over the lifetime of those vehicles is 733 and the present value of the lives saved would be 328 – 1,146 lives with 90 percent certainty. Table XII-6 summarizes the simulated results.

Table XII-6
Simulated Present Value of Lives Saved – FARS-Centered Model

At No Discount	**Present Value of Lives Saved**
Mean	1,073
90 % Certainty	408 - 1,688
At 3% Discount	
Mean	899
90 % Certainty	402 – 1,405
At 7% Discount	
Mean	733
90 % Certainty	328 –1,146

The second fatal target population is derived from CDS and the corresponding effectiveness rates were derived from crash data and injury curves. The CDS/injury-curve results are called CDS/curve model results. The model format is the same as the FARS-centered model. The difference is in the input of target population and effectiveness. In contrast to a constant target population for the FARS-centered model, the target population for this CDS/curve model is normally distributed (Table XII-1) and differs by compliance option. The effectiveness has a very different probability distribution (Figure 1) from the normal distribution as used in the FARS-centered model.

After about 100,000 trials, this model forecasts that the proposal would save an average of 689 lives for Option 1, 1,038 lives for Option 2, and 1,042 for Option 3. With a 90 percent certainty, the proposed rule would save 677 – 694 lives for Option 1, 493 – 1,584 for Option 2, and 484 – 1,594 for Option 3. Table XII-7 summarizes these statistics.

At a 3 percent discount rate, the average present value of lives saved is 577 lives for Option 1; 869 lives for Option 2; and 872 for Option 3. With a 90 percent certainty, the present value of lives saved is 567 – 581 for Option 1; 413 – 1,326 for Option 2; and 405 – 1,335 for Option 3.

At a 7 percent discount rate, the average present value of lives saved is 471 lives for Option 1; 710 lives for Option 2; and 712 for Option 3. With a 90 percent certainty, the present value of lives saved is 463 – 474 lives for Option 1; 337 – 1,082 for Option 2; and 331 – 1,089 for Option 3.

Table XII-7
Simulated Present Value of Lives Saved – CDS/Curve Model

	Option 1	Option 2	Option 3
At No Discount			
Mean	689	1,038	1,042
90 % Certainty	677 - 694	493 - 1,584	484 – 1,594
At 3% Discount			
Mean	577	869	872
90 % Certainty	567 - 581	413 – 1,326	405 – 1,335
At 7% Discount			
Mean	471	710	712
90 % Certainty	463 – 474	337 – 1,082	331 – 1,089

Based on Tables XII-6 and XII-7, the FARS-centered model generated slightly more benefits than found by the CDS/curve model. However, the FARS-centered estimated benefits are most comparable to Option 3 of the CDS/curve model. This is expected because the FARS-centered model, which addresses injuries to all body regions, would be more similar to Option 3 of the CDS/curve model which includes a wider range of sensors. This also indicates a certain degree of stability in the benefit estimates.

Net Benefits

The CDS/curve model is the only one that includes both fatalities and injuries and thus it is used to generate the net benefit results. More importantly, the model imitates the actual process for the point benefit estimates conducted in the previous cost-effectiveness chapters. The variables and their probability distributions were described in the "Quantifying Uncertainty and Constant Factors" section. Table XII-8 summarizes the simulated results after about 100,000 trials.

Based on the simulated results as shown in Table XII-8 (see page XII-22), with 90 percent certainty, the proposal would save about 764 to 1,321 equivalent lives for Option 1; 1,043 – 1,824 for Option 2; and 1,058 – 1,844 for Option 3. All three options produce a cost per equivalent fatality of no more than $5.5 million with a high degree of certainty. Table XII-8 also shows that the estimated mean net benefits of the proposal range from $4.1 to $4.8 billion (B) depending on the compliance technology options. Furthermore, with 90 percent certainty, all three compliance options of the proposal would produce a positive net benefit of $1.7 - $7.5 B for Option 1; $1.4 to $9.5 B for Option 2; and $0.9 - $9.1 B for option 3.

At a 3 percent discount rate, the proposal would save about 640 - 1,106 equivalent lives (present value) for Option 1; 873 – 1,527 for Option 2; and 886 – 1,544 for Option 3. All three options produce a cost per equivalent fatality of no more than $5.5 million with a 100 percent certainty. If $3.5 million is the threshold, Option 1 would meet it with a 100 percent certainty, Option 2 with 96 percent, Option 3 with 83 percent. At this discount rate, the estimated mean net benefits of the proposal are: $3.2 B for Option 1; $3.5 B for Option 2; and $3.0 B for Option 3. With 90 percent certainty, all three compliance options of the proposal would produce a positive net benefit of $1.1 - $6.1 B for Option 1; $0.7 - $7.4 B for Option 2; and $0.2 - $7.0 B for option 3.

At a 7 percent discount rate, the proposal would save about 522 - 903 equivalent lives (present value) for Option 1; 713 – 1,246 for Option 2; and 723 – 1,260 for Option 3. All three options produce a cost per equivalent fatality of no more than $5.5 million with a 100 percent certainty. If $3.5 million is the threshold, Option 1 would meet it with a 100 percent certainty. Option 2 would meet this threshold by a 96 percent certainty. However for Option 3, the certainty is only 42 percent. Finally, at this discount rate the proposal would still produce positive mean net benefits ranging from $1.8 to $2.3 billion (B). However, Options 2 and 3 would produce a possible negative net benefit. With 90 percent certainty, the proposal would produce the net benefits of $0.6 - $4.6 B for Option 1; -$0.4 to $5.5 B for Option 2; and -$0.5 to $5.1 B for option 3. All three options produce positive net benefits with a high level of certainty.

Summary

The proposed rule is very favorable regardless of the implementing options. Even with the large discount rate of 7 percent, all three options would have over a 100 percent chance to produce a cost per equivalent fatality of no more than $5.5 million. However, if the threshold is $3.5 million, Option 3 would be less certain than Options 1 and 2 to be cost-effective. In addition, this proposal would generally produce positive mean net benefits and positive overall net benefits with a very high level of certainty.

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 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. Their difference is also due to the rounding process. The mean net benefit calculations in Table XII-8 are based on the value of a statistical life of $5.5 million with a range of $1 to $10 million. In Chapter VII, the net benefits estimates are calculated at point estimates of $3.5 million and $5.5 million. Thus, the results in Chapter VII for net benefits at $5.5 million will be closer to the net benefits calculated in this probabilistic uncertainty analysis summarized in Table XII-8, which have a mean of $5.5 million.

Table XII-8a
Simulated Cost-Effectiveness and Net Benefits

No Discounting	**Option 1**	**Option 2**	**Option 3**
Mean Total Cost*	$1.6B	$3.0B	$3.6B
90% Certainty for Total Costs*	$1.4 – 1.7 B	$2.8 – 3.3 B	$3.3 – 3.9 B
Mean Equivalent Lives Saved	1,041	1,434	1,441
90% Certainty for Equivalent Lives Saved	764 – 1,321	1,043 – 1,824	1,058 – 1,844
Mean CE	$1.5 M	$2.2 M	$2.5 M
Certainty that CE <= $3.5 M	100%	100%	97%
Certainty that CE <= $5.5 M	100%	100%	100%
Mean Net Benefits	$4.1 B	$4.8 B	$4.3 B
90% Certainty for Net Benefits	$1.7 - $7.5 B	$1.4 - $9.5 B	$0.9 – $9.1 B
Certainty that Net Benefits > $0	100%	99%	97%
At 3% Discount Rate			
Mean Equivalent Lives Saved (present value)	872	1,201	1,207
90% Certainty for Equivalent Lives Saved (present value)	640 – 1,106	873 – 1,527	886 – 1,544
Mean CE	$1.8 M	$2.6 M	$3.0 M
Certainty that CE <= $3.5 M	100%	96%	83%
Certainty that CE <= $5.5 M	100%	100%	100%
Mean Net Benefits	$3.2 B	$3.5 B	$3.0 B
90% Certainty for Net Benefits	$1.1 - $6.1 B	$0.7 - $7.4 B	$0.2 – $7.0 B
Certainty that Net Benefits > $0	99%	97%	94%
At 7% Discount Rate			
Mean Equivalent Lives Saved (present value)	711	980	985
90% Certainty for Equivalent Lives Saved (present value)	522 – 903	713 – 1,246	723 – 1,260
Mean CE	$2.2 M	$3.2 M	$3.7 M
Certainty that CE <= $3.5 M	100%	75%	42%
Certainty that CE <= $5.5 M	100%	100%	100%
Mean Net Benefits	$2.3 B	$2.3 B	$1.8 B
90% Certainty for Net Benefits	$0.6 - $4.6 B	-$0.4 - $5.5 B	-$0.5 to $5.1 B
Certainty that Net Benefits > $0	99%	93%	86%

B = billion; M = million; CE = cost per equivalent life saved
* same for all discount rates