U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

DOT HS 810 748 **January 2007**

NHTSA Technical Report

An Evaluation of Side Impact Protection

FMVSS 214 TTI(d) Improvements and Side Air Bags

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT HS 810 748		

4. Title and Subtitle

AN EVALUATION OF SIDE IMPACT PROTECTION

FMVSS 214 TTI(d) Improvements and Side Air Bags

5. Report Date

January 2007

6. Performing Organization Code

7. Author(s)

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8. Performing Organization Report No.

9. Performing Organization Name and Address

Evaluation Division; National Center for Statistics and Analysis
National Highway Traffic Safety Administration
Washington, DC 20590

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Agency Name and Address

Department of Transportation
National Highway Traffic Safety Administration
Washington, DC 20590

13. Type of Report and Period Covered

NHTSA Technical Report

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Federal Motor Vehicle Safety Standard 214, "Side Impact Protection" was amended to assure occupant protection in a 33.5 mph crash test and phased-in to new passenger cars during model years 1994-1997. A Thoracic Trauma Index, TTI(d) is measured on Side Impact Dummies seated adjacent to the impact point. Manufacturers upgraded side structures and affixed padding in cars to improve TTI(d). Later, they installed two types of side air bags – torso bags and head air bags – for additional occupant protection in cars and LTVs. Statistical analyses of 1993-2005 crash data from the Fatality Analysis Reporting System (FARS) and the General Estimates System (GES) estimate fatality reductions for these technologies.

- Average TTI(d) improved in 2-door cars from 114 in 1981-1985 to 44 in 214-certified cars with side air bags, and in 4-door cars from 85 to 48.
- TTI(d) improvements without side air bags reduced fatality risk for nearside occupants in multivehicle crashes by an estimated 33 percent in 2-door cars and 17 percent in 4-door cars.
- Torso plus head air bags reduce fatality risk for nearside occupants by an estimated 24 percent; torso bags alone, by 12 percent.
- TTI(d) improvements, torso bags and head-curtain air bags could have saved an estimated 2,934 lives in calendar year 2003 if every car and LTV on the road had been equipped with them.

17. Key Words

NHTSA; FARS; NASS; GES; FMVSS; statistical analysis; evaluation; benefits; effectiveness; fatality reduction; crashworthiness; angle collision

18. Distribution Statement

Document is available to the public at the Docket Management System of the U.S. Department of Transportation, http://dms.dot.gov, Docket Number 27588.

19. Security Classif. (Of this report)	20. Security Classif. (Of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	178	

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LIST OF ABBREVIATIONS

ABS	Antilock brake system
AIS	Abbreviated Injury Scale
ANPRM	Advance Notice of Proposed Rulemaking
BMW	Bayerische Motoren Werke
CATMOD	Categorical models procedure in SAS
df	Degrees of freedom
DOT	United States Department of Transportation
EU	European Union
FARS	Fatality Analysis Reporting System (a census of fatal crashes in the United States since 1975)
FMH	Free-motion headform
FMVSS	Federal Motor Vehicle Safety Standard
GES	General Estimates System of NASS
GM	General Motors
GVWR	Gross Vehicle Weight Rating (specified by the manufacturer, equals the vehicle's curb weight plus maximum recommended loading)
HIC	Head Injury Criterion
IIHS	Insurance Institute for Highway Safety
IR	Information Request (from NHTSA)
kph	Kilometers per hour
LTV	Light trucks and vans (includes pickup trucks, SUVs, minivans and full-sized vans)
MDB	Moving deformable barrier
mph	Miles per hour

msec	Milliseconds
MY	Model year
NASS	National Automotive Sampling System (a probability sample of police-reported crashes in the United States since 1979, investigated in detail)
NCAP	New Car Assessment Program (consumer information supplied by NHTSA on the safety of new cars and LTVs, based on test results, since 1979)
NHTSA	National Highway Traffic Safety Administration
NICB	National Insurance Crime Bureau
NPRM	Notice of Proposed Rulemaking
NVPP	R.L. Polk's National Vehicle Population Profile
PSU	Primary sampling unit
RF	Right-front
SAS	Statistical analysis software produced by SAS Institute, Inc.
SID	Side impact dummy
SUV	Sport utility vehicle
TTI	Thoracic Trauma Index
TTI(d)	Thoracic Trauma Index for the dummy in a side-impact test
VIN	Vehicle Identification Number
VMT	Vehicle miles of travel

ACKNOWLEDGEMENTS

I owe special thanks to the three researchers who peer-reviewed a draft of this report:

1) Mr. Dainius J. Dalmotas, Chief, Crashworthiness Research, Motor Vehicle Standards and Research, Transport Canada (Retired), Gatineau, Quebec, Canada

2) Mr. John L. Jacobus, Mechanical Engineer, National Highway Traffic Safety Administration (Retired), Silver Spring, MD

3) Mr. Anders Lie, Vehicle Safety Specialist, Swedish National Road Administration, Borlange, Sweden

This study estimates the fatality-reducing effectiveness of side air bags, based on statistical analyses of crash data. The National Highway Traffic Safety Administration (NHTSA) plans to use the statistical results when it estimates the benefits of a future final rule: the addition of a pole test to Federal Motor Vehicle Safety Standard (FMVSS) No. 214, Side Impact Protection. Because of the potential cost impacts of the proposed regulation, the report contains "highly influential scientific information" as defined by the Office of Management and Budget's (OMB) "Final Information Quality Bulletin for Peer Review" (available at www.whitehouse.gov/omb/inforeg/peer2004/peer_bulletin.pdf). Therefore, the report had to be peer-reviewed in accordance with the requirements of both Sections II and III of OMB's Bulletin.

The peer-review process differed from the type used by journals. The effort by Messrs. Dalmotas, Jacobus and Lie was essentially consultation to identify shortcomings in the draft and help NHTSA strengthen the report. We in NHTSA specifically requested and arranged for these three reviewers. The review process is on record – their comments on the draft may be viewed in the NHTSA docket for this report. The publication of this report does not necessarily imply that they "endorsed" it or agreed with its findings. You may read their comments in the docket to see what they agreed or disagreed with in the draft. We have tried to address all of the comments in our revised report (but we did not send it back to them for a second round of review). The text and footnotes of the report single out some of the reviewers' comments that instigated additions or revisions to the analyses.

EXECUTIVE SUMMARY

Side air bags with head protection, such as torso bags with head curtains reduce fatality risk in side impacts by an estimated 24 percent for the nearside occupant, the person seated adjacent to the struck side of the vehicle. That benefit adds to the effect of improved side structures and padding built into passenger cars during the 1980s and 90s that had already reduced fatality risk for nearside occupants by 33 percent in 2-door cars and 17 percent in 4-door cars.

In 2003, over 9,000 fatalities, approximately 29 percent of all occupant fatalities in cars and LTVs (light trucks and vans – i.e., pickup trucks, sport utility vehicles, minivans and full-size vans) began with a side impact. The side of a vehicle, especially the door area adjacent to the occupant is intrinsically a vulnerable spot: there is limited space and structure between the occupant and the outside. Side impacts can also be difficult to avoid. Even the most prudent driving on our part cannot eliminate the risk that another vehicle will fail to yield, run a red light or turn without warning across our path.

Since the 1970's, the National Highway Traffic Safety Administration (NHTSA), the manufacturers and others in the safety community have worked hard to reduce fatality risk in side impacts, especially for the most vulnerable occupant, the "nearside" occupant: the driver in a left-side impact and the right-front passenger in a right-side impact. The effort resulted in the four tangible improvements in side impact protection that are evaluated in this report:

1. Upgrading the side **structure** of passenger cars to slow down and reduce the extent of door intrusion into the passenger compartment after a side impact. Improvements include redesigning or strengthening the beams that horizontally reinforce the doors; the pillars, sills, and roof rails that surround the doors; and the cross-members or seat structures that resist lateral crush.

2. Installation of thick, energy absorbing **padding** within the door structure to reduce the probability of occupant injury after the door interior contacts the occupant.

And two types of **side air bags**:

3. **Torso air bags** that deploy from the seat or the door to provide an energy-absorbing cushion between the occupant's torso and the vehicle's side structure. Torso air bags cover a much larger impact area and absorb more energy than padding.

4. **Head-protection air bags** that complement the torso bags by cushioning head impacts with the side structure and possibly barring occupant ejection through side windows. Head protection may consist of:

    a. "Torso/head combination bags" that deploy from the seat to protect the torso but also extend upward far enough to protect the head impact zones around the side window, or

    b. "Head curtains" or "inflatable tubular structures" that drop down from the roof rail into the side-window area, separately from the torso bags.

During the 1980's, NHTSA and the safety community developed a procedure for assessing injury risk in side impacts, including:

- A crash test configuration simulating a severe intersection collision in which a fast-moving vehicle strikes a slow-moving vehicle in the door, at a right angle.
- A Moving Deformable Barrier (MDB) simulating a generic striking vehicle.
- A Thoracic Trauma Index (TTI) that predicts the severity of thoracic injuries when occupants' torsos contact the interior side surface of the struck vehicle.
- A Side Impact Dummy (SID) on which TTI can be reliably measured in side impact tests. The injury score measured on the dummy is called TTI(d).

In 1990 NHTSA amended Federal Motor Vehicle Safety Standard (FMVSS) 214, *Side Impact Protection* for passenger cars, adding a 33.5 mph impact by an MDB into the side of the car and limiting TTI(d) for a SID in the nearside position up to a maximum of 90 in 2-door cars and 85 in 4-door cars. The requirement was phased-in to passenger cars during model years 1994 to 1997 and subsequently extended to LTVs, effective in model year 1999, limiting TTI(d) to 85.

The manufacturers redesigned structures and/or affixed padding to substantially reduce average TTI(d) during and, to some extent, even before the 1994-1997 phase-in of FMVSS 214. But their actions varied from model to model. Many 2-door cars, with their long, vulnerable door areas, received extensive structural reinforcement or other redesign, whereas some of the heavier 4-door cars and most LTVs needed little or no change to meet FMVSS 214. In many cars, manufacturers improved TTI(d) well beyond the NHTSA requirements.

Manufacturers have continued to improve side impact protection by installing side air bags and/or upgrading side structures as they redesigned their cars. Torso bags first appeared on production vehicles in 1996 and head-protection air bags in 1998. By model year 2003, nearly 30 percent of new cars were equipped with torso bags and nearly 20 percent with head-protection air bags. NHTSA does not require side air bags, but encourages all improvements to side impact protection, including side air bags, by informing consumers about the performance of new vehicles. The agency's New Car Assessment Program (NCAP) includes a rating system of one star (worst) to five stars (best) on a side impact test. *Buying a Safer Car* brochures specify what make-models are equipped with torso and/or head air bags. The information is available to consumers on the agency's web site, www.safercar.gov.

TTI(d) performance at the 33.5 mph test speed of FMVSS 214 demonstrates how much cars have improved over the years. In 2-door cars, TTI(d) for front-seat occupants has improved, on the average, from 114 in baseline 1981-1985 models to 44 in models equipped with side air bags and meeting FMVSS 214: amazing progress on a difficult safety problem.

This report investigates if the improvements in side impact protection have saved lives in actual crashes, based on statistical analyses of crash data. The Government Performance and Results Act of 1993 and Executive Order 12866 require agencies to evaluate the benefits of their existing regulations. The statistical analyses use calendar year 1993-2005 crash data from the Fatality

Analysis Reporting System (FARS) and the General Estimates System (GES) of the National Automotive Sampling System (NASS). The analyses are divided into two main sections:

- Effect of TTI(d) improvements by structure and padding (without side air bags) on the fatality risk of front-seat occupants (drivers and right-front passengers) in passenger cars. Many of the improvements date to the mid-1990s. By now, the cars have been on the road for nearly a decade. While there is a fair amount of uncertainty, the results are essentially final in the sense that most of the eventual data are already in hand.
    - A parallel analysis for compact pickup trucks did not show a statistically significant effect.
- Effect of side air bags – torso bags and/or head-protection air bags – for front-seat occupants of cars and LTVs. Side air bags, especially head air bags began to appear in large numbers only after 2000. Analyses already show statistically significant results, but more data are on the way. The findings of this report will be updated periodically during the next five years.
    - Side air bags are principally designed to protect nearside occupants but might conceivably also benefit farside occupants: the driver in a right-side impact and the right-front passenger in a left-side impact. Statistical analyses separately focus on nearside and farside occupants.

The main findings of this report are that structural improvements and padding for cars, and side air bags for cars and LTVs have significantly reduced occupants' fatality risk. The two types of side air bags – torso bags and head-protection air bags – make substantial and complementary contributions to fatality reduction for nearside occupants. Head curtains (or inflatable tubular structures) also appear to have a significant benefit for farside occupants of passenger cars. The public will obtain the most protection if they have all of these improvements: structures and padding that meet or exceed the requirements of FMVSS 214, torso bags and head curtains. The combined effects are impressive, amounting to a 42 percent cumulative fatality reduction in 2-door cars, and a 30 percent reduction in 4-door cars.

The findings and conclusions of the statistical analyses are the following:

SIDE IMPACT PERFORMANCE OVER THE YEARS

The risk of chest injury in a side impact is measured on a specially designed side impact dummy during a crash test in the FMVSS 214 configuration, a 33.5 mph impact by a moving deformable barrier into the side of the test vehicle. Accelerations measured on the upper and lower ribs and lower spine are combined into a Thoracic Trauma Index for the dummy - TTI(d). TTI(d) gauges occupants' injury risk in nearside impacts: the lower the TTI(d), the lower the risk of injury. Reductions in the average TTI(d) of the many vehicles NHTSA has tested over the years demonstrate improved safety in side impacts.

- TTI(d) for front-seat occupants in the FMVSS 214 test configuration, by model year, averaged:

	2-Door Cars	**4-Door Cars**
FMVSS 214 requirement	*90*	*85*
Actual performance:		
1981-1985 baseline TTI(d)	114	85
1993-1996, but not yet 214 certified	95	71
1994-2003, 214-certified – no side air bags	69	63
1996-2003, 214-certified – with side air bags	44	48

- In 2-door cars, TTI(d) improved by 45 units since 1981-1985 without side air bags and an additional 25 units with side air bags, for a total of 70. Average performance was originally much worse than the FMVSS 214 requirement and is now much better.

- In 4-door cars, TTI(d) improved by 22 units since 1981-1985 without side air bags and an additional 15 units with side air bags, for a total of 37. Average performance was once about the same as the FMVSS 214 requirement and is now much better.

- TTI(d) performance used to be much worse in 2-door cars than in 4-door cars; it is now nearly the same.

EFFECT OF TTI(d) IMPROVEMENT WITHOUT SIDE AIR BAGS IN PASSENGER CARS

- During the model year 1994-1997 phase-in of FMVSS 214, approximately:
  - 56 percent of cars received substantial structural modifications, usually accompanied with padding.
  - 21 percent received padding with minor structural modifications.
  - 6 percent received padding only.
  - 17 percent remained essentially unchanged from previous model years.
- This report identifies 15 make-models that substantially improved TTI(d), by a known amount, without side air bags: from an average of 85 to 62, a 23-unit improvement. Fatality risk of nearside front-seat occupants in multivehicle crashes decreased by a statistically significant 18 percent in these models (90 percent confidence bounds, 7 to 28 percent).
- For passenger cars with TTI(d) in the below-90 range, each unit improvement of TTI(d) without side air bags is associated with an estimated 0.863 percent fatality reduction for nearside occupants in multivehicle crashes (confidence bounds, 0.33 to 1.46 percent).
  - The fatality reductions for nearside occupants in single-vehicle crashes and for farside occupants were not statistically significant.
- For pre-FMVSS 214, 2-door cars with TTI(d) in the 90+ range, each unit improvement of TTI(d) was associated with an estimated 0.927 percent fatality reduction for all occupants in side impacts (confidence bounds, 0.52 to 1.33 percent).
- In 2-door cars, the cumulative effect of reducing TTI(d) from 114 (1981-1985 baseline) to 69 (post-FMVSS 214 without side air bags) is a 33 percent fatality reduction for nearside occupants in multivehicle crashes (confidence bounds, 18 to 47 percent).
- In 4-door cars, the cumulative effect of reducing TTI(d) from 85 (1981-1985 baseline) to 63 (post-FMVSS 214 without side air bags) is a 17 percent fatality reduction for nearside occupants in multivehicle crashes (confidence bounds, 7 to 27 percent).
- TTI(d) improvement by structures and padding in passenger cars saved an estimated 803 lives in calendar year 2003.
- If every passenger car on the road in 2003 had been equipped with these improvements, they would have saved an estimated 1,143 lives.

EFFECT OF SIDE AIR BAGS IN CARS AND LTVs

Nearside occupants

- Torso bags plus head protection in passenger cars reduces the fatality risk of nearside front-seat occupants in single- and multivehicle crashes by a statistically significant 24 percent (90 percent confidence bounds, 4 to 42 percent).[1]
    - The data also show a statistically significant fatality reduction in LTVs and suggest that the effectiveness may be the same as in cars.
    - The available data do not show a difference in fatality reduction between the two types of head air bags: head curtains (or inflatable tubular structures) and torso/head combination bags.
- Torso bags alone reduce the fatality risk of nearside occupants in passenger cars by an estimated 12 percent (confidence bounds, -3 to +23 percent).
    - Current data also suggest similar reductions for LTV occupants.
- Through 2005, there were few vehicles equipped with head curtains only (no torso bags): not enough for a separate statistical analysis. However, the preceding results suggest that torso bags and head air bags are both effective in nearside impacts and make approximately equal contributions to fatality reduction.

Farside occupants

- Specific mechanisms whereby side air bags mitigate injuries in farside impacts have not yet been widely demonstrated or quantified by testing.
- Nevertheless, statistical analyses of FARS and GES data show significant reductions of fatality risk for head curtains plus torso bags in farside impacts to passenger cars.
- Furthermore, analyses of life-threatening injuries to farside occupants in passenger cars without side air bags suggest that head curtains or inflatable tubular structures could have benefited unrestrained occupants – or even belted drivers if no passenger had been sitting between them and the right side of the car – because:
    - Head curtains would have deployed and covered areas responsible for a large proportion of the life-threatening injuries, and

[1] A small portion of this effectiveness may actually be due to energy-absorbing materials (other than air bags) installed to meet the FMVSS 201 upgrade of head-impact protection. NHTSA will evaluate FMVSS 201 in the future; this report only addresses its interaction with side air bags. In many make-models, the introduction of head air bags coincided with FMVSS 201 certification; nevertheless, the energy-absorbing materials remained largely unchanged in the year that head air bags were introduced, and for that reason could not have accounted for a large portion of the fatality reduction for those make-models in that year.

- In most of those impacts, the head curtains would still have been at least partially inflated at the time the farside occupant contacted them.

- A 24 percent fatality reduction is estimated (same as for nearside occupants) for head curtains plus torso bags in farside impacts to passenger cars – for unrestrained occupants and for belted drivers riding alone in the front seat.

- With the limited crash data available to date, no consistently significant fatality reduction was found and, for now, none is claimed in farside impacts for:

  - LTVs (with any type of side air bags),

  - Torso bags alone or torso/head combination bags in cars, or

  - Belted occupants, when somebody sits between them and the far side.

Occupant ejection

- Head curtains reduced the risk of fatal occupant ejection in side impacts by a statistically significant 30 percent.

  - Through model year 2003, head air bags in passenger cars were only designed to deploy in side impacts. Head curtains with rollover sensors began to appear in selected LTVs during mid-model year 2002. Crash data were not sufficient to evaluate to what extent this promising technology reduces ejections in rollover crashes.

Overall

- Side air bags could have saved an estimated 1,791 lives in calendar year 2003 if every passenger car and LTV on the road had been equipped with head curtains (or inflatable tubular structures) plus torso bags and if every LTV on the road had been equipped with torso bags plus head protection. However, the number of lives saved if all vehicles on the road were to have side air bags in a future year would be smaller than 1,791, since:

  - The long-term shift of the on-road fleet from cars to LTVs will reduce the number of potentially fatal side impacts because LTVs are less vulnerable, when struck in the side, than cars.

  - The increasing proportion of vehicles equipped with Electronic Stability Control will further reduce the number of potentially fatal side impact and rollover crashes by preventing these crashes altogether.

  The estimation of future lives saved is beyond the scope of this report, but will be addressed in NHTSA's forthcoming Final Regulatory Impact Analysis to add a pole test to FMVSS 214.

COMBINED EFFECT OF IMPROVED STRUCTURE, PADDING, AND SIDE AIR BAGS

- Side impact protection could have saved an estimated 2,934 lives in calendar year 2003 if every car on the road had been equipped with head curtains, torso bags and FMVSS 214 side structures/padding, and if every LTV on the road had been equipped with torso bags plus head protection.

- Relative to 1981-1985 baseline cars, the combination of head curtains, torso bags and FMVSS 214 side structures/padding reduces fatality risk of drivers and right-front passengers in all side impacts by:

    - 42 percent in 2-door cars.

    - 30 percent in 4-door cars.

- In LTVs, torso bags plus head protection reduce fatality risk of drivers and right-front passengers in all side impacts by 15 percent.

CHAPTER 1

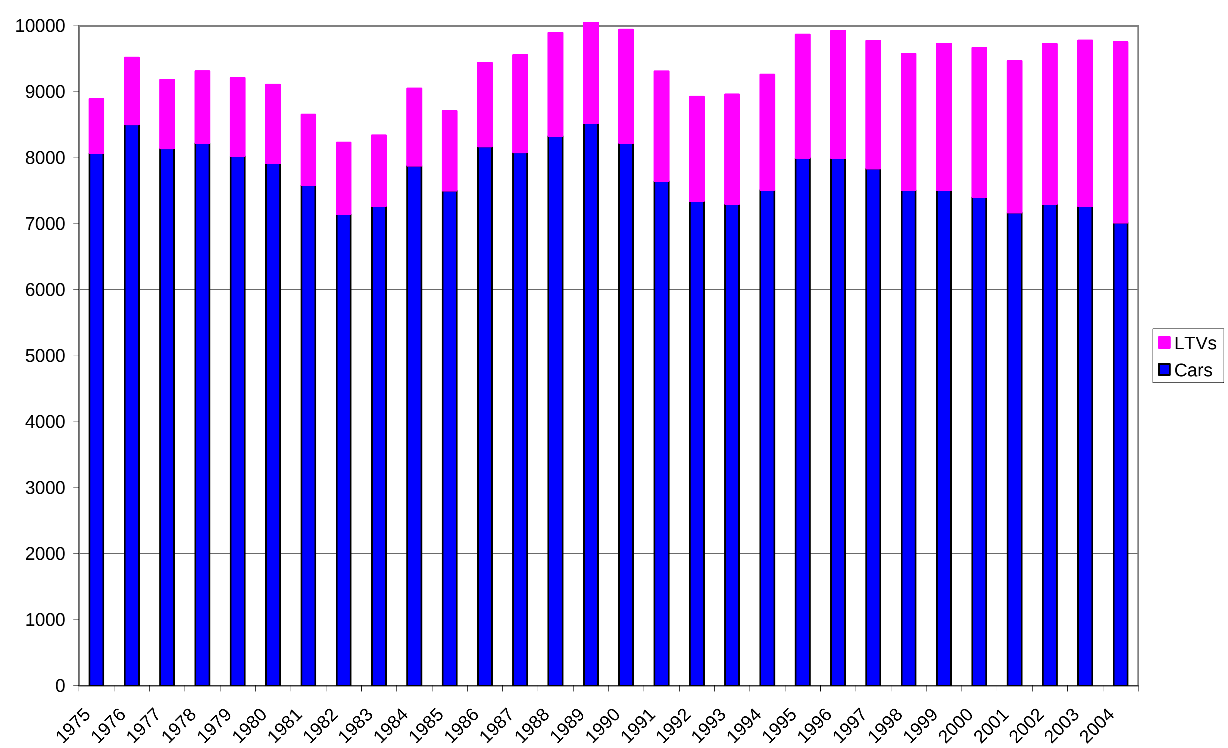
OCCUPANT PROTECTION IN SIDE IMPACTS

Federal Motor Vehicle Safety Standard (FMVSS) 214, amended in 1990 to assure occupant protection in a dynamic test that simulates a side impact collision, is one of the most important safety regulations issued by NHTSA. The requirement was phased-in to passenger cars during model years 1994 to 1997. Crash data are now available to evaluate whether this regulation and the vehicle modifications that improve performance in the side impact test, including upgraded structure, padding and side air bags are effective in reducing fatality risk in actual side impact crashes of production passenger cars.

1.1 The side impact problem in passenger cars

Number of fatalities: Figure 1-1 shows that side impacts accounted for close to 9,000 occupant fatalities per year in passenger cars and LTVs (light trucks and vans, including pickup trucks, SUVs, minivans and full-size vans under 10,000 pounds GVWR), year after year, from 1975 through 2004:[2]

Figure 1-1: Car and LTV Occupant Fatalities in All Side Impacts, 1975-2004



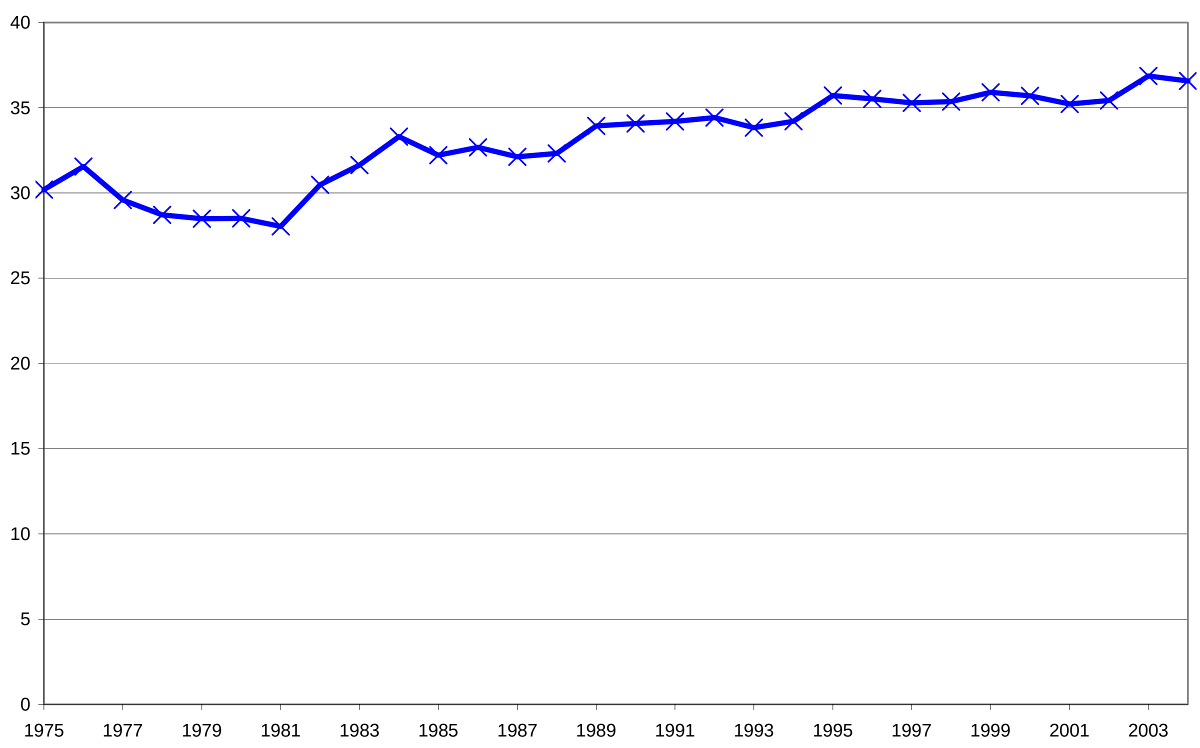
[2] Dainius Dalmotas recommended trend analyses of side impact fatalities in his review of this report. Figures 1-1 – 1-9 address issues he raised, but the data in these figures were generated, at NHTSA, especially for this report.

The number of fatalities stayed about the same while vehicle miles of travel (VMT) more than doubled. The proportion of these fatalities in LTVs increased in parallel with the increasing ratio of LTVs to cars in the on-road fleet. Nevertheless, LTVs are under-represented because they are less vulnerable in side impacts than cars. For example, in 2004, only 28 percent of the side impact fatalities were occupants of LTVs, even though LTVs accounted for 40 percent of the on-road fleet.[3]

Figure 1-1 documents that side impacts accounted for 7,000-8,500 occupant fatalities per year in passenger cars throughout 1975-2004; however, they gradually declined from 8,000 to 7,000 in 1996-2004. The decline could reflect the gradual aging of the on-road fleet (older cars are driven fewer miles per year) and also, conceivably, the benefits of safety measures, including the measures evaluated in this report.

Proportion of fatalities: Figure 1-2 shows that side impacts account for a gradually increasing share of the occupant fatalities in passenger cars, rising from 30 percent of the fatalities in 1975 to 37 percent in 2004.

Figure 1-2: Percent of Car Occupant Fatalities that Are in Side Impacts, 1975-2004

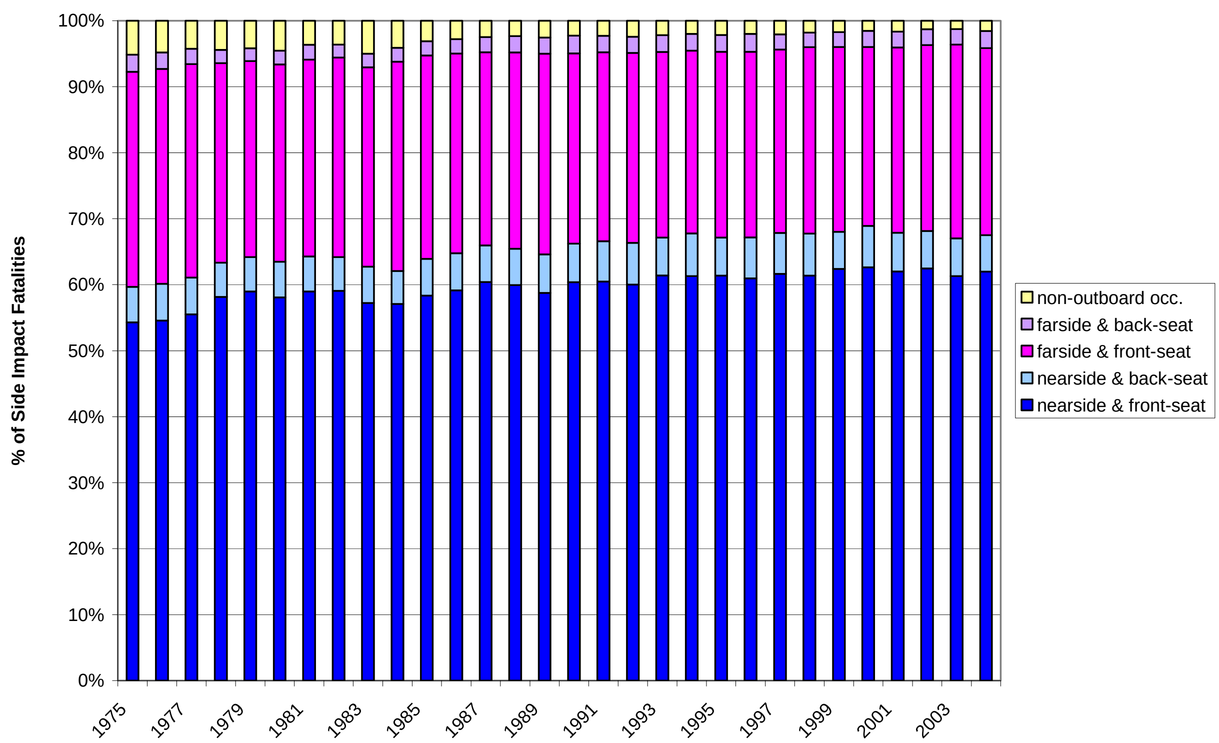


[3] Overall VMT increased from 1,328 billion miles in 1975 to 2,963 billion miles in 2004; 2740 of 9755 side impact fatalities in 2004 were in LTVs, from Figure 1-1; 89,938,581 of 223,213,958 passenger vehicles registered in 2004 were LTVs, according to *Traffic Safety Facts 2004*, NHTSA Report No. DOT HS 809 919, Washington, 2005, pp. 15, 22 and 24.

In every year, side impacts ranked second only to frontal impacts as a cause of occupant fatalities in passenger cars. Technologies such as safety belts and frontal air bags are more effective in preventing fatalities in rollovers and/or frontals than in side impacts. Thus, deaths in lateral impacts, while shrinking in absolute numbers, now account for a larger share of the fatalities.

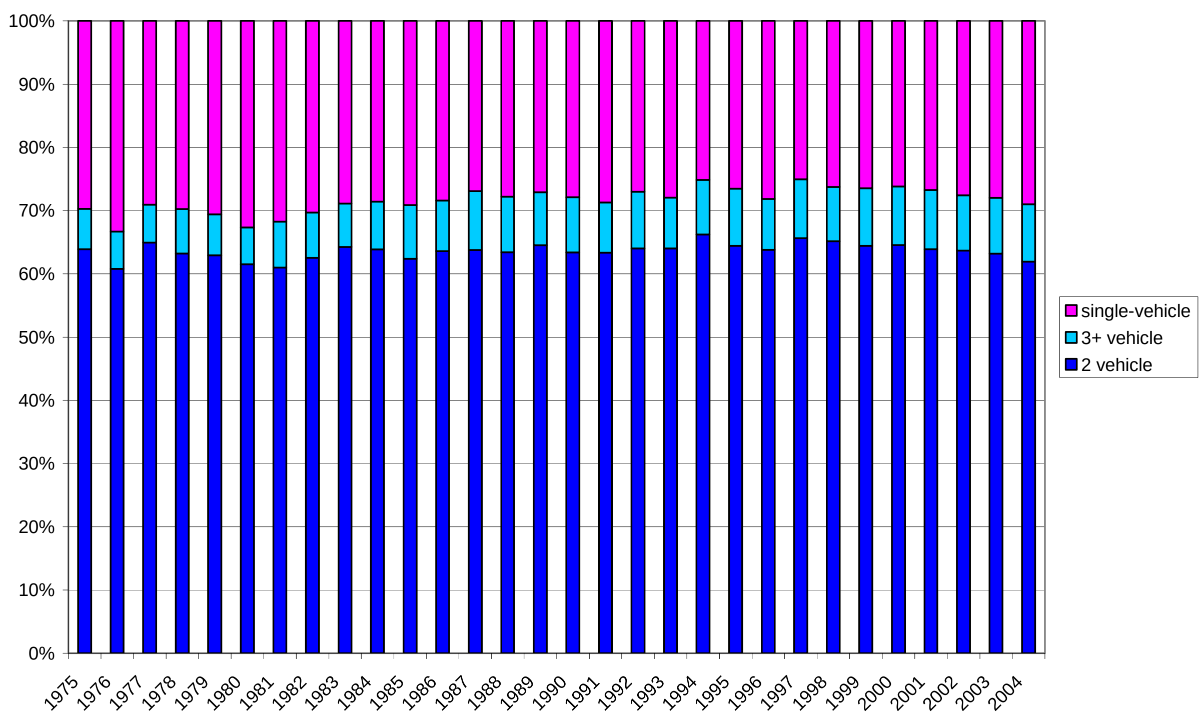
Nearside vs. farside: Occupants are especially at risk if they are sitting on the side of the car that was struck: drivers in left-side impacts and right-front passengers in right-side impacts. For these **nearside** occupants, only a car's relatively narrow side structure, comprising the doors, sill, roof rail and supporting pillars stands between the occupant and the impacting vehicle or object. That contrasts with frontal, rear and **farside** impacts where there is initially considerable distance and structure between the occupant and the contact. Figure 1-3 shows the ratio of nearside to farside fatalities is close to 2:1, year after year. Especially after 1990, close to 70 percent of the fatalities are nearside occupants, and just over 60 percent are front-outboard occupants (drivers and right-front passengers) in nearside impacts.

Figure 1-3: Nearside vs. Farside Fatalities, Passenger Cars, 1975-2004



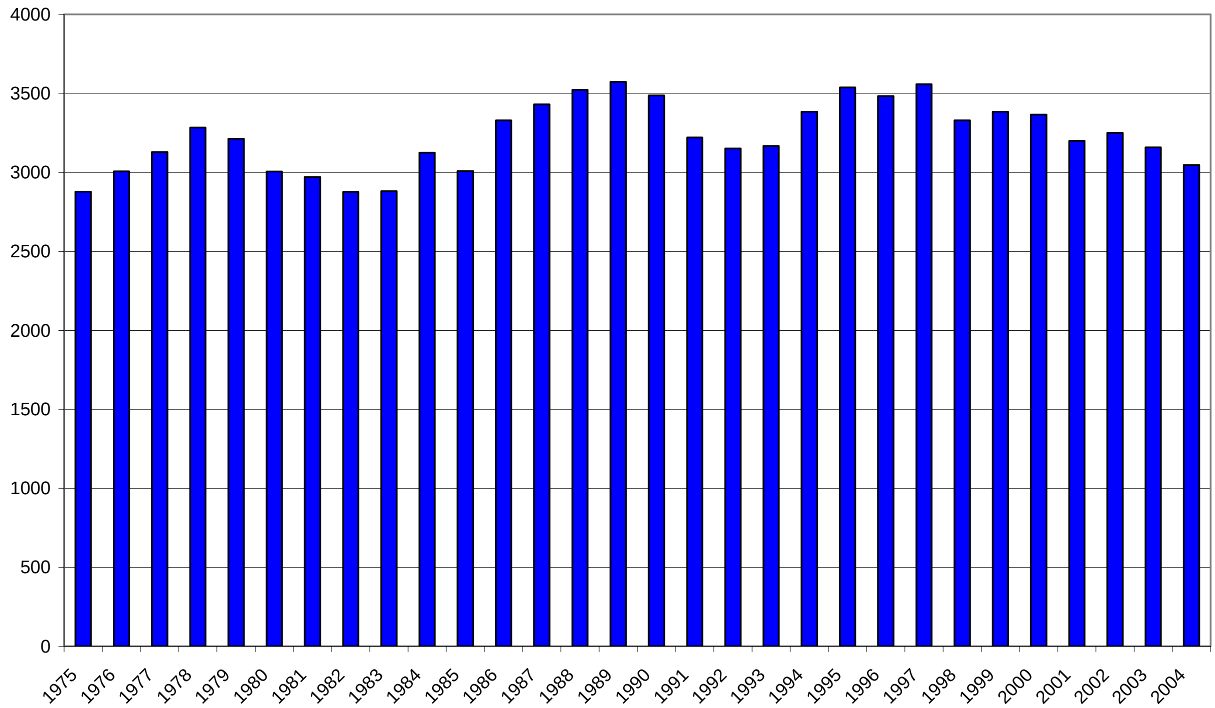
Multi- vs. single-vehicle crashes: Side impacts can occur when vehicles from two different roads collide front-to-side at an intersection, or when one vehicle, while turning or changing lanes, crosses the path of another vehicle on the same road. Occasionally, a vehicle can spin out of control and slide sideways into the path of another moving vehicle. The side of a car can impact a fixed object such as a tree or pole if the car runs off the road and spins out of directional control, sliding side-first into the object. The roadway departure may precede the loss of directional control, or vice-versa. Figure 1-4 indicates throughout 1975-2004 that close to 70 percent of the nearside, front-seat fatalities in passenger cars occurred in multivehicle crashes (involving 2 vehicles, or in some cases 3 or more vehicles), with perhaps some downward trend since 1997:

Figure 1-4: Percent of Nearside Fatalities that Are in Multi-Vehicle Crashes
Car Front-Seat Occupants, 1975-2004



Nearside front-seat fatalities in multivehicle crashes: Figure 1-5 shows that 3,000-3,500 drivers and right-front passengers of cars died each year in nearside impacts by other vehicles. As will be discussed later, they are a primary target population for the improvements envisioned in the 1990 amendment to FMVSS 214. Fatalities declined from an average of 3,500 in 1995-1997 to about 3,000 in 2004.

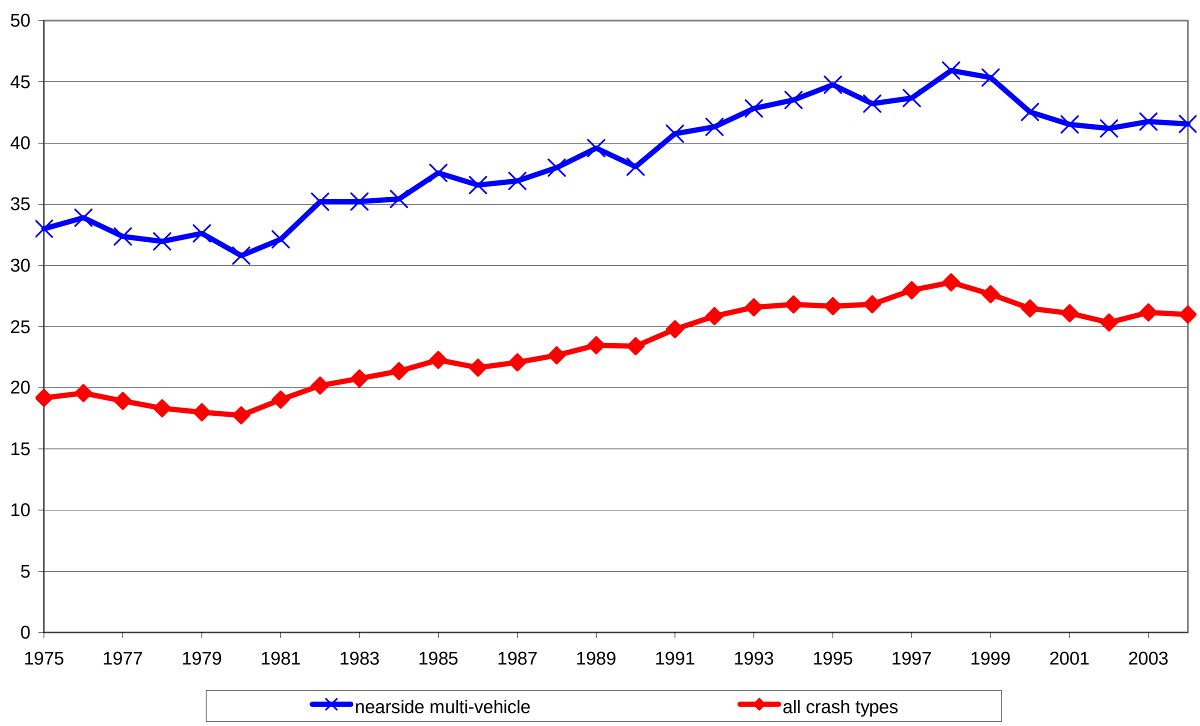
Figure 1-5: Nearside Fatalities in Multi-Vehicle Crashes
Front-Seat Occupants of Passenger Cars, 1975-2004



Older occupants: Figure 1-6 shows that a large proportion of the drivers and right-front passengers of cars killed in nearside impacts by another vehicle are 55 years or older, ranging from 33 percent in 1975 to 40-45 percent throughout 1991-2004 (blue line). By contrast, in all types of crash involvements of cars, including frontals and rollovers, only 19 percent of all driver and right-front passenger fatalities in 1975 and 25-30 percent in 1991-2004 are 55 years or older (red line). Older occupants are over-represented in the side impacts primarily because older drivers have more difficulty recognizing when it is safe to turn across oncoming traffic or enter an intersection. It is also conceivable that older occupants are especially susceptible to injury in this type of impact. Nevertheless, Figure 1-6 demonstrates that:

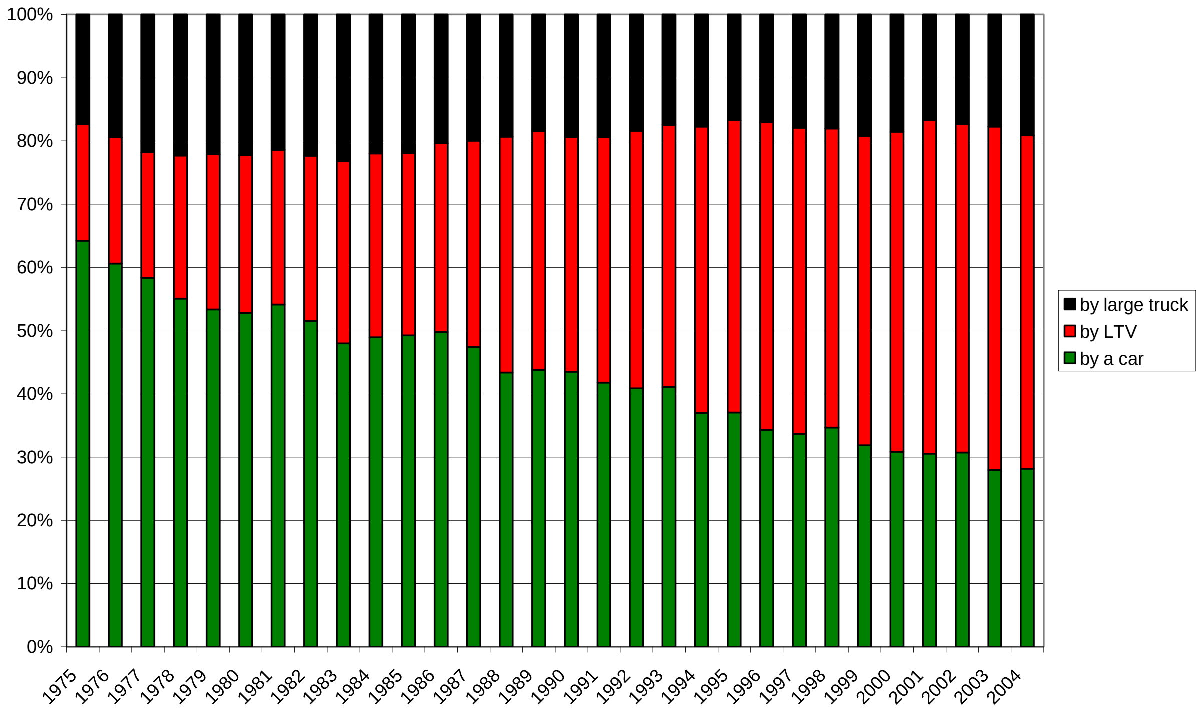
- The increasing proportion of older victims in nearside impacts since 1975 almost exactly parallels a corresponding increase in all types of crashes, both a consequence of an aging driver population (rather than a problem unique to nearside impacts).
- There has been little net change in the last 15 years.

Figure 1-6: Percent of Victims Age 55 Years and Older Nearside Impacts by a Vehicle vs. All Types of Crashes Front-Seat Fatalities in Passenger Cars, 1975-2004



Striking vehicle type: One characteristic of nearside impacts did change dramatically during 1975-2004. Figure 1-7 shows that, in 1975, over 60 percent of the nearside fatalities to car occupants in two-vehicle crashes involved an impact by another passenger car and less than 20 percent were impacts by LTVs. By 2004, less than 30 percent were impacts by passenger cars and over 50 percent were impacts by LTVs. Impacts by heavy trucks accounted for 20 percent of the fatalities throughout 1975-2004. The shift to LTVs, of course, reflects the growing percentage of LTVs in the on-road fleet. Nevertheless, LTVs are over-represented as striking vehicles in fatal crashes relative to their share of registrations. In 2004, for example, there were 89,938,581 LTVs on the road and 133,275,377 passenger cars, yet LTVs outnumbered cars as the striking vehicle by more than 5 to 3.[4] Factors such as greater mass, height and rigidity make LTVs more aggressive than cars as a "bullet" vehicle in side impacts.[5]

Figure 1-7: Striking Vehicle Type in 2-Vehicle Crashes
Nearside Fatalities to Front-Seat Occupants of Cars, 1975-2004



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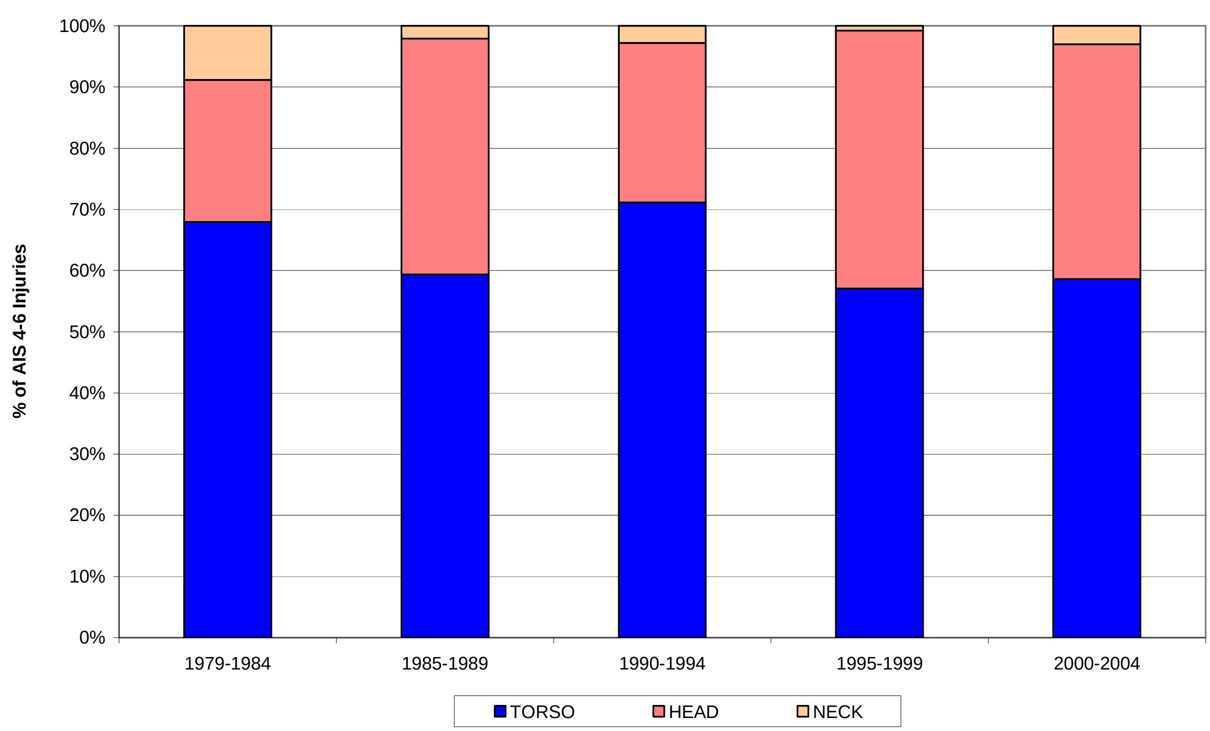
[4] *Ibid*., pp. 22 and 24.

[5] Kahane, C.J., *Vehicle Weight, Fatality Risk and Crash Compatibility of Model Year 1991-99 Passenger Cars and Light Trucks,* NHTSA Technical Report No. DOT HS 809 662, Washington, 2003, Chapter 6; Gabler, H.C. and Hollowell, W.T., "NHTSA's Vehicle Aggressivity and Compatibility Research Program," Paper No. 98-S3-O-01, *Proceedings of the 16th International Technical Conference on the Enhanced Safety of Vehicles*, Report No. DOT HS 808 759, Washington, 1998; Gabler, H.C. and Hollowell, W.T., *The Aggressivity of Light Trucks and Vans in Traffic Crashes*, Paper No. 980908, Society of Automotive Engineers, Warrendale, PA, 1998.

Injury distribution by body region: During a side impact by another vehicle, the car's side structure has limited capacity to absorb energy. The structure is deflected into the passenger compartment nearly at the impact speed of the "bullet" vehicle and soon makes contact with the nearside occupant, especially the occupant's torso, because it tends to be on the same level as the striking vehicle's front. The Crashworthiness Data System (CDS) of the National Automotive Sampling System (NASS) documents the injuries in various types of crashes during 1979-2004. In frontal impacts (a benchmark), 56 percent of the life-threatening injuries – levels 4-6 on the Abbreviated Injury Scale (AIS) – to drivers and right-front passengers of passenger cars were to the occupant's torso and 44 percent to the head or neck. But in nearside impacts by another vehicle, 63 percent of life-threatening lesions are torso injuries. By contrast, in nearside impacts with fixed objects, which may contact the car from floor to ceiling, 50 percent were torso injuries. And in farside impacts, where occupants are in less danger of immediate contact with intruding structures but may be tossed around the vehicle, only 46 percent were torso injuries.

The shift from passenger cars to LTVs as the predominant striking vehicle raises the question that head injuries could have increased substantially because the occupant's head is more likely to contact the elevated hood of the striking LTV than the low hood of a striking car.[6] Figure 1-8, however, indicates that the ratio of head to torso injuries stayed more or less the same throughout 1979-2004 for front-seat occupants of passenger cars struck in the near side by other vehicles:

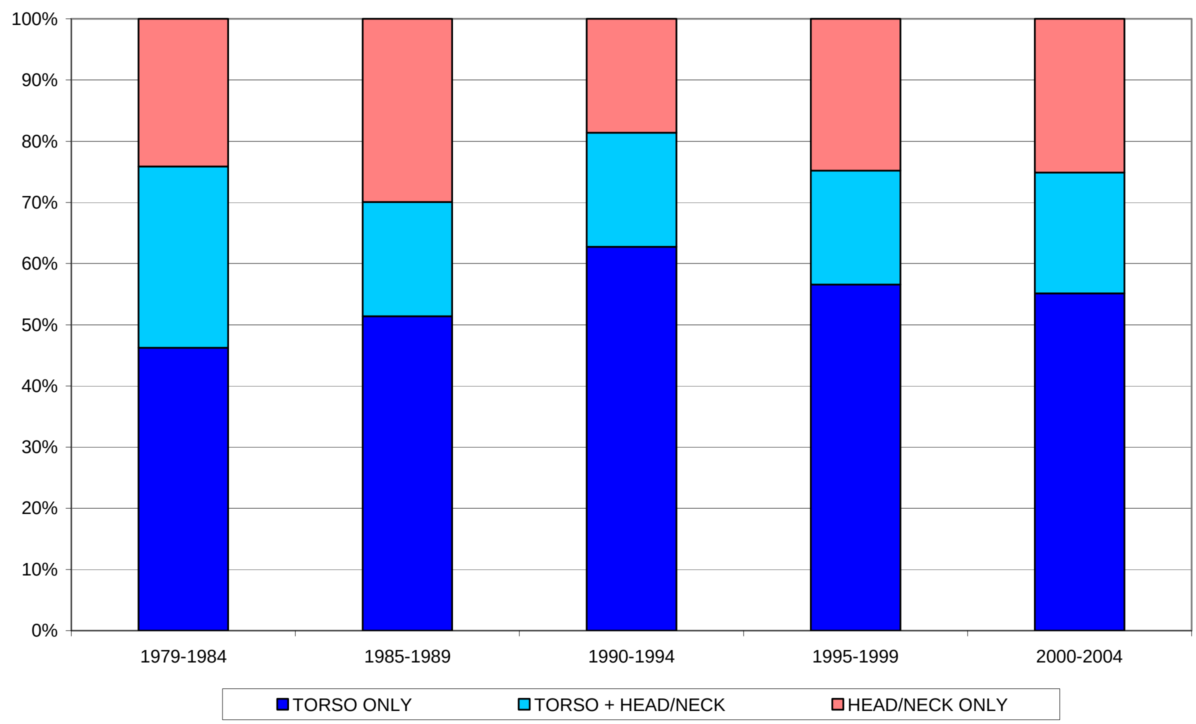
Figure 1-8: Distribution of AIS 4-6 Injuries by Body Region
Nearside Impacts by a Vehicle, Front-Seat Occupants of Passenger Cars, CDS 1979-2004



[6] Dalmotas specifically asked it in his peer review.

Figure 1-8 analyzes the distribution of individual AIS 4-6 **injuries**, possibly more than one per occupant. Figure 1-9 performs the same analysis at the **person** level. A person who has one or more AIS 4-6 injuries may have such injuries to the torso only, the head/neck only or possibly to both. Figure 1-9 shows that, throughout 1979-2004, close to 55 percent of the front-outboard occupants with life-threatening injuries in nearside impacts by other vehicles had such injuries to the torso only, and close to 76 percent had a torso injury plus, possibly a head or neck injury. Just 24 percent had head or neck injuries alone. In frontal crashes, 38 percent had only head or neck injuries; in nearside impacts with fixed objects and in all farside impacts, 48 percent.

Figure 1-9: Distribution of Occupants by Body Regions with AIS 4-6 Injuries
Nearside Impacts by a Vehicle, Front-Seat Occupants of Passenger Cars, CDS 1979-2004



Belt effectiveness: Even though safety belts are quite effective in almost every other type of crash, they are of little help in a nearside impact, directly into the occupant compartment, by another vehicle. Torso contact with the intruding side structure is likely to occur whether an occupant is belted or not. NHTSA found only a non-significant 5 percent reduction in fatality risk for belt use in nearside multivehicle crashes, as compared to statistically significant reductions of 21 percent in nearside impacts with fixed objects, 39 percent in farside impacts, 50 percent in frontals, and 74 percent in rollovers.[7]

[7] Kahane, C.J., *Fatality Reduction by Safety Belts for Front-Seat Occupants of Cars and Light Trucks*, NHTSA Technical Report No. DOT HS 809 199, Washington, 2000, pp. 28-32; specifically, pp. 31-32 explain that safety belts are more effective in nearside impacts with fixed objects than in nearside impacts by other vehicles primarily because the former are far more likely to involve occupant ejection.

1.2 Side door beams: an early measure to protect occupants

Before 1969, the side doors of passenger cars were nearly empty shells of sheet metal, offering little protection to occupants in side impacts. **Side door beams**, running longitudinally inside the door, were a first step to provide some crush resistance and structural strength. During the 1960's, Hedeen and Campbell at General Motors developed the beams and a static test for measuring a door's crush resistance. They were installed in MY 1969 full-size GM cars. By then, NHTSA had announced its intention to regulate side door strength with an Advance Notice of Proposed Rulemaking (ANPRM) in October 1968. The first version of Federal Motor Vehicle Safety Standard (FMVSS) 214 was issued as a Final Rule in October 1970, with an effective date of January 1, 1973. It sets strength requirements for side doors, based on a static test of crush resistance: a rigid steel cylinder is gradually forced into the door, and it must encounter crush resistance exceeding various levels that depend on the depth of the crush and the weight of the car. All cars were equipped with side door beams meeting FMVSS 214 at some point during MY 1969-1973.[8]

A typical side door beam is a metal bar of channel (fluted) design, 8 inches wide, located inside the door, about 10 inches above the sill, running the length of the door, attached to the door frame at each end. In MY 1979-1981, beams weighed from 5 to 7 pounds per door in 4-door cars, and 10 to 21 pounds per door in 2-door cars. Any structure added within the door is welcome. By putting some crush on the front of the striking vehicle and/or transmitting force to the remainder of the struck vehicle and accelerating it sideways, the structure can reduce the amount of intrusion toward the occupant and slow down the rate of that intrusion. Nevertheless, researchers suspected that a 5-21 pound beam, stretching from one end of the door to the other without much support in the middle, would have limited power to resist a severe and perpendicular impact into the middle of the door by a 2,000-5,000 pound vehicle. The 10-inch gap between the beam and the sill is an additional weak point.

NHTSA evaluated the fatality and injury reduction of side door beams in 1982, based on statistical analyses of crash data.[9] As expected, the beams had little or no effect on the fatality risk of nearside occupants in multivehicle crashes. However, they were rather effective in some other situations. In single-vehicle side impacts, fatality risk was reduced by 14 percent for nearside and farside occupants, and when this group of crashes was further limited to impacts with a single fixed object, fatality reduction was 23 percent. Here, rather than merely absorbing energy, the beam acts like an internal "guard rail" to allow a car to slide past a pole or tree, with a longer, shallower crush pattern on the car. Integrity of the side structure was better preserved. Beams were also effective in somewhat lower-speed multivehicle crashes, reducing the risk of nonfatal injuries. When the damage was centered in the occupant compartment area, side door beams reduced nearside occupants' hospitalizations by a statistically significant 25 percent. NHTSA estimates that side door beams saved nearly 500 lives in single-vehicle crashes of

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[8] Kahane, C.J., *Lives Saved by the Federal Motor Vehicle Safety Standards and Other Vehicle Safety Technologies, 1960-2002,* NHTSA Technical Report No. DOT HS 809 833, Washington, 2004, pp. 136-140; Kahane, C.J., *An Evaluation of Side Structure Improvements in Response to Federal Motor Vehicle Safety Standard 214*, NHTSA Technical Report No. DOT HS 806 314, Washington, 1982, pp. 100-108; Hedeen, C.E. and Campbell, D.D., *Side Impact Structures*, Paper No. 690003, Society of Automotive Engineers, New York, 1969; *Federal Register* 33 (October 5, 1968): 14971, 35 (October 30, 1970): 16801.

[9] Kahane (1982).

passenger cars in 2002, and have also prevented about 9,500 nonfatal hospitalizations per year in single- and multivehicle crashes.[10]

NHTSA extended the static strength test of FMVSS 214 to LTVs, effective September 1, 1993. In single-vehicle side impacts, side door beams reduced fatality risk in LTVs by a statistically significant 19 percent. NHTSA's evaluation estimated that side door beams would eventually save 151 lives per year in LTVs, when all LTVs on the road have the beams.[11]

1.3 The dynamic test requirement for FMVSS 214

By the late 1970's, if not earlier, researchers suspected that side door beams alone would not sufficiently attenuate intrusion in a severe side impact by another vehicle to reduce fatality risk to the nearside occupant of the struck car. At a public Side Impact Conference on January 31, 1980, NHTSA outlined its plans to upgrade FMVSS 214 with a dynamic test.[12] The new regulation aimed to reduce fatality risk to the nearside occupant when a car is struck in the door area by another vehicle - the configuration responsible for the largest group of side impact fatalities – and especially to reduce fatal thoracic injuries.

Unlike some earlier FMVSS that could draw upon extensive information about existing test procedures and safety technologies, the FMVSS 214 upgrade necessitated many years of research, analysis and testing by NHTSA and others in the safety community. Researchers from the United States and other countries considered numerous alternative injury criteria, dummies, test configurations, etc. NHTSA's selected approach comprised:

- A review of crash data, indicating that the archetypal side impact fatality in the 1980's involved a fast-moving car striking a slow-moving car in the door, at a right angle: a typical intersection collision.
- A review of injury data, indicating that a large proportion of the nearside occupants' life-threatening injuries occurred when the sides of their torsos contacted the interior side surface (most frequently the door) of the car. (Head injuries, as noted above, are also a frequent cause of fatalities in side impacts, but were not the principal focus of this rulemaking process. Recent and ongoing rulemaking to address head injuries are discussed in Section 1.4.)
- The Thoracic Trauma Index (TTI) was found to be an excellent predictor of thoracic injury severity in experimental side impacts to cadavers.[13] $TTI = ½ (G_R + G_{LS})$, where G_R is the greater of the peak accelerations of either the upper or the lower rib, expressed in g's and G_{LS} is the lower spine (T12 vertebra) peak acceleration. Pelvic g's are an additional injury criterion, but TTI is the key predictor of life-threatening injuries.

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[10] Kahane (2004), pp. 140 and 217.

[11] Walz, M.C., *Evaluation of FMVSS 214 Side Impact Protection for Light Trucks: Crush Resistance Requirements for Side Doors*, NHTSA Technical Report No. DOT HS 809 719, Washington, 2004; *Federal Register* 56 (June 14, 1991): 27427.

[12] *Side Impact Conference*, NHTSA Report No. DOT HS 805 614, Washington, 1980.

[13] *Final Regulatory Impact Analysis - New Requirements for Passenger Cars to Meet a Dynamic Side Impact Test FMVSS 214*, NHTSA Publication No. DOT HS 807 641, Washington, 1990.

- Development of a Side Impact Dummy (SID) on which TTI (as well as pelvic g's) can be reliably measured in a side impact test configuration. The injury score measured on the dummy is called TTI(d).
- A Moving Deformable Barrier (MDB) was developed to represent a generic 3000-pound passenger vehicle. The test procedure simulates an MDB moving 30 mph hitting, at a right angle, the door area of a subject vehicle, traveling 15 mph. (It is accomplished by having the MDB travel at 33.54 mph at an angle of 63 degrees with respect to the longitudinal centerline of a stationary test vehicle. The wheels of the MDB are "crabbed" 27 degrees toward the rear of the test vehicle to obtain a right-angle contact.)
- Testing various production 1980-1988 passenger cars to learn the baseline distribution of TTI(d). Some baseline testing continued after the Final Rule was issued in 1990, up to model year 1993, just before the phase-in period for the MDB test requirement.
- Demonstration of two technologies, **structure** and **padding**, that, singly or in combination can significantly improve (i.e., decrease) TTI(d) from its baseline levels in production vehicles.
- Regulatory analysis[14] to estimate the lives saved by decreasing TTI(d) to various levels, and the extent of vehicle modifications needed to secure those levels – and, finally –
- On October 30, 1990, NHTSA issued the Final Rule amending FMVSS 214 to phase in a dynamic test of side impact protection during model years 1994-1997. FMVSS 214 recognizes the greater difficulty of protecting occupants in 2-door cars. FMVSS 214 allows TTI(d) up to 90 in 2-door cars, but limits 4-door cars to 85. FMVSS 214 also includes test limits on pelvic g's and has door retention requirements to reduce occupant ejection. At least 10 percent of passenger cars produced between September 1, 1993 and August 31, 1994 had to meet the standard; at least 25 percent of cars produced between September 1, 1994 and August 31, 1995; at least 40 percent of cars between September 1, 1995 and August 31, 1996; and all cars after September 1, 1996. During that phase-in period, manufacturers declared ("self-certified") what make-models complied with FMVSS 214. NHTSA advised the public on what models were certified.[15]
- The regulatory analysis projected that at least 512 lives would be saved per year if TTI(d) improved from its baseline levels in cars of the mid-1980's to 90 or better in all 2-door cars and 85 or better in all 4-door cars.[16]

The new version of FMVSS 214, however, retained the original "static" test in view of the demonstrated effectiveness of side door beams in collisions with fixed objects. Furthermore, the side door beam, often strengthened, continued to be an integral part of the structures used to meet the dynamic test requirement.

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[14] *Ibid*.
[15] *Federal Register* 55 (October 30, 1990): 45752; *NHTSA Hails Safety Features in Model Year 1994 Passenger Cars and Light Trucks and Vans*, Press Release No. NHTSA 38-93, U. S. Department of Transportation, Office of the Assistant Secretary for Public Affairs, Washington, 1993.
[16] *Final Regulatory Impact Analysis,* p. IV-62; includes 498 lives saved by mitigating thoracic injuries plus 14 lives saved by preventing occupant ejection through better door retention; a deduction was made for projected increases in safety belt use.

Side Impact NCAP In addition to compliance tests that assure cars meet the minimum requirements of FMVSS 214, NHTSA provides consumer information on vehicle performance in side impacts. The information is collected as part of NHTSA's New Car Assessment Program (NCAP) and posted on the agency's web site, www.safercar.gov . The agency uses a rating system of one star (worst) to five stars (best) for front-outboard and rear-outboard occupants, based primarily on TTI(d) but also taking into account pelvic g's. In the NCAP tests, the MDB strikes the side of the target vehicle at 38.5 mph, 5 mph faster than in the FMVSS 214 test. The purpose of the higher speed is to differentiate more clearly between average and superior performance in severe crashes. The side NCAP program started shortly after September 1, 1996, the date when all new cars were required to meet the dynamic side impact test of FMVSS 214. Side NCAP has provided an additional incentive to decrease TTI(d) well below the requirements set by FMVSS 214 and to seek further improvements in TTI(d) as time goes on.

European regulations and NCAP The European Union approved a side impact safety regulation, EU Directive 96/27/EC, in October 1996. It applies to all new or redesigned models manufactured after October 1, 1998, and all other vehicles manufactured after October 1, 2003. Like FMVSS 214, a MDB is launched into a stationary target vehicle occupied by one dummy in the front seat. However, the test speed is slightly lower (50 kph) and there is no crab angle – i.e., no attempt is made at simulating the movement of the target vehicle. The MDB is lighter (2,095 lbs), smaller and softer than in FMVSS 214, although 0.8 inches higher off the ground. As in FMVSS 214, successful test performance is determined by dummy injury criteria. However, both the test dummy and injury criteria differ from those in FMVSS 214. SID is capable of measuring acceleration of the ribs, spine and pelvis. A dummy called Euro SID is used instead of SID. It measures force and displacement as well as acceleration-based readings. The regulation limits the Head Injury Criterion (HIC) to 1000, rib deflection to 42 mm (1.7 in.), the Viscous Criterion (V*C) to 1 m/s, abdominal force to 2.5 kN (562 lbs) and the force on the pubic symphysis region to 6 kN (1350 lbs).[17]

The Euro NCAP program began side impact testing in 1996 and published its first results in 1997. Unlike the United States, the NCAP test speed is the same as the EU regulation (50 kph). Initially, there were four star ratings. In 2000, Euro NCAP added a voluntary pole test that can improve the side impact score and potentially add a fifth star to the rating for side impact. In 2003, the more advanced Euro SID 2 superseded the Euro SID dummy.[18]

Side impact ratings by the Insurance Institute for Highway Safety (IIHS) began in 2003. Their MDB weighs 3,300 pounds (300 pounds more than FMVSS 214) and its front end simulates the height and other characteristics of a pickup truck or SUV. The test speed is slightly

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[17] Anders Lie recommended a discussion of European regulations and Euro NCAP in his review of this report. *NHTSA Plan for Achieving Harmonization of the U.S. and European Side Impact Standards, Report to Congress, April 1997*, NHTSA Docket No. NHTSA-1998-3935-1, 1998. The Viscous Criterion is calculated from combined rib displacement and velocity.

[18] *Creating a Market for Safety – 10 Years of Euro NCAP,* European New Car Assessment Programme, Brussels, 2005, accessible from www.euroncap.com ; McNeill, A., Haberl, J., Holzner, M., Schoeneburg, R., Strutz, T. and Tautenhahn, U., "Current Worldwide Side Impact Activities – Divergence versus Harmonisation and the Possible Effect on Future Car Design," Paper No. 05-0077, *Proceedings 19th International Technical Conference on the Enhanced Safety of Vehicles*, NHTSA Report No. DOT HS 809 825, Washington, 2005, accessible from www-nrd.nhtsa.dot.gov/departments/nrd-01/esv/19th/esv19.htm .

lower (50 kph) and there is no crab angle. The dummies are SID-II 5th percentile females, considered at greater risk than the 50th percentile male. IIHS rates vehicles good, acceptable, marginal or poor, based on: injury criteria for the head/neck, torso and pelvis/leg; movements of the dummy's head; and the vehicle's structural performance.[19]

1.4 Technologies to protect occupants in side impacts

Circa 1990, NHTSA believed that manufacturers would be able to meet Standard 214 (with just passing scores) by installing only padding in many cars. Some cars might need structural modifications, especially 2-door cars. Other cars might not need any change at all, especially the larger 4-door cars. Manufacturers might modify structure more extensively if they aimed to drop TTI(d) well below the FMVSS 214 requirement. By the mid-1990's, the industry was already well on its way to developing air bags that deploy and offer additional protection in side impacts.

Padding reduces the probability of occupant injury, given that the door structure has contacted the occupant. The padding is located within the door at points where hip or chest contacts are likely. It is thick plastic foam - not a soft pad – capable of absorbing significant energy at a force-deflection rate safe for occupants. Without the padding, more rigid components would immediately contact the occupant.

Structure modifications, beyond the side door beams installed in response to the original, static test, slow down and reduce the extent of door intrusion into the passenger compartment. They included substantially strengthening the beams themselves and/or the pillars, sills, roof rails, seats or cross-members of a car, and strengthening the overlap between doors and pillars, sills, etc. The test procedure enables manufacturers to identify the weakest points in the structure of their prototype cars and reinforce them as needed.

Side-impact air bags

Torso air bags During the 1990's, manufacturers and suppliers developed air bags that deploy from the seat or the door to provide an energy-absorbing cushion between the occupant's torso and the vehicle's side structure during lateral impacts. Conceptually, torso air bags do the same thing as padding, but they do a lot more of it. Volvo made them standard on all their MY 1996 cars, while Audi, BMW and Cadillac began to furnish them as standard equipment on some 1997 models and offer them as options on others. By MY 2001, nearly 30 percent of new cars were equipped with torso air bags, and that percentage stayed about the same in 2002 and 2003. They can substantially improve TTI(d), as we shall see in Section 1.5. NHTSA's annual *Buying a Safer Car* brochures inform the public what make-models are equipped with torso air bags.[20]

Head-protection air bags Measures to decrease TTI(d) are first and foremost designed to mitigate torso injuries, although they may also reduce head injuries. Head-protection air bags, on the other hand, specifically target head injuries, which account for 37-54 percent of life-

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[19] www.iihs.org/ratings .

[20] *Buying a Safer Car 2000*, NHTSA Publication No. DOT HS 809 046, Washington, 2000; *Buying a Safer Car 2001*, NHTSA Publication No. DOT HS 809 152, Washington, 2000; *Buying a Safer Car 2002*, NHTSA Publication No. DOT HS 809 409, Washington, 2002; *Buying a Safer Car*, NHTSA Publication No. DOT HS 809 546, Annual publication, 2003-2005.

threatening lesions in various types of side impacts (Section 1.1). They may have an additional benefit as a barrier to occupant ejection through side windows. By the mid-1990's, auto industry suppliers were developing head-protection airbags for meeting the proposed FMVSS 201. On July 29, 1998, NHTSA amended FMVSS 201 (occupant protection in interior impact) to facilitate the introduction of these air bags.[21] BMW introduced head air bags as standard equipment in some lines in model year 1998, and by 2001, many of the large manufacturers offered them as standard or optional equipment on various models. By MY 2003, nearly 20 percent of new passenger cars were equipped with some type of head air bag. On May 17, 2004, the agency issued a Notice of Proposed Rulemaking (NPRM) to amend FMVSS 214, proposing to add a 20 mph side impact with a pole, at a 75-degree angle (i.e., 15 degrees forward of a purely lateral impact). The proposed three-year phase-in dates would start four years after publication of a Final Rule. NHTSA anticipates that head air bags would generally be installed to meet the new requirement.[22]

There are currently two distinct types of head-protection air bags:

- "Curtains" or "tubes (inflatable tubular structures)" that drop down from the roof rail into the side-window area. These are separate from any torso air bags in the vehicle, although they usually share components such as sensors and the control module. Initially, all vehicles equipped with head curtains or tubes also had torso air bags, but starting in 2001, some vehicles were equipped with head curtains only, and no torso air bags.
- "Torso/head combination bags" that deploy from the seat to protect the torso but also extend upward far enough to protect the head impact zones around the side window.

NHTSA's annual *Buying a Safer Car* brochures inform the public what make-models are equipped with head-protection air bags, and the type of bags.[23]

The head injury protection upgrade for FMVSS 201

On August 14, 1995, NHTSA issued a Final Rule extending the head injury protection requirements of FMVSS 201. It established a new list of target areas in the vehicle's upper interior, including the A-, B- and other pillars, the front and rear roof header, the roof side rails, and the upper roof, among others. It is not a side impact standard *per se*, because these structures can be sources of life-threatening head injuries in any crash mode, and they are located on the front, rear and top as well as the sides of the vehicle. Nevertheless, side impacts account for many of the injuries. In a 15 mph impact test of a free-motion headform (FMH) into any of these targets, the Head Injury Criterion (HIC) may not exceed 1000 for any 36-millisecond

[21] *Federal Register* 63 (August 4, 1998): 41451; Recognizing that the 15 mph headform test might be a problem in target areas where the undeployed air bag is stored (and, furthermore, an inappropriate test if the bag usually deploys at that speed), NHTSA offered an alternative compliance procedure. Manufacturers have the option to reduce the speed of the headform test to 12 mph on target areas where the bag is stored, provided they can meet an 18 mph lateral (90 degree) crash test for the full vehicle into a pole – with HIC < 1000. The pole test simulates a side impact with a fixed object (e.g., a tree, utility pole or concrete abutment) and it measures the severity of the head impact with the deployed bag.
[22] *Federal Register* 68 (May 17, 2004): 27990.
[23] *Buying a Safer Car 2000-2005.*

period. Impacts may be directed from a range of vertical and horizontal angles, not just head-on.[24]

The evaluation of FMVSS 201 is a high priority for NHTSA, but outside the scope of this report, because many years of detailed data on injuries by body region and injury source will be needed.[25] In this report, we are concerned with FMVSS 201 primarily to the extent that it could interact, or be a confounding factor in our evaluations of TTI(d) improvements, torso bags and head air bags.

Manufacturers were offered a choice of several alternative phase-in schedules during the four years from September 1, 1998 to September 1, 2002. For example, they could certify the new requirements on at least 10 percent of cars and LTVs manufactured during the first year, at least 25 percent during the second year, at least 40 percent during the third year, at least 70 percent during the fourth year, and all cars and LTVs manufactured on or after September 1, 2002.

Manufacturers could certify to FMVSS 201 by:

- Adding energy-absorbing materials such as padding, ribbing, or an "egg-crate" honeycomb configuration around target areas, or using a thicker roof liner.
- Adding head air bags; in fact, as mentioned above, NHTSA's 1998 amendment of FMVSS 201 facilitated the use of air bags.
- A combination of both, relying on energy-absorbing materials in target areas not covered by the air bag.
- Little or no change, if a pre-standard vehicle could already meet FMVSS 201 at most or all target areas.

Given those alternatives, it is not surprising that the phase-in period for FMVSS 201 overlapped the initial installations of head air bags. Many make-models were certified to FMVSS 201 with energy-absorbing materials one or more years before they offered head air bags – i.e., head impact protection was upgraded in two distinct, temporally separate stages. But many others certified at the same time or even after they offered them – usually, but not always signifying that the entire upgrade, air bags plus energy-absorbing materials (if any) was implemented at once.[26] But FMVSS 201 certification (without head air bags) also overlapped the initial installation of torso bags only in quite a few make-models and sometimes even coincided with "second generation" TTI(d) improvements to structures and padding that took place after the initial 1994-1997 phase-in of FMVSS 214.

[24] *Federal Register* 60 (August 18, 1995): 43031; Kahane (2004), p. 51.
[25] *National Highway Traffic Safety Administration Evaluation Program Plan, Calendar Years 2004-2007*, NHTSA Report No. DOT HS 809 699, Washington, 2004, p. 8.
[26] Possible reasons for not certifying a make-model to FMVSS 201 until a year or more after offering head air bags could include: (1) head air bags were optional, not furnished on every vehicle; (2) the manufacturer, being ahead of the phase-in schedule, had no obligation to certify this make-model, even though it would have complied with FMVSS 201; (3) the manufacturer had to make additional changes in subsequent years before the vehicle met FMVSS 201.

NHTSA's cost analyses of FMVSS 201 comprise 15 make-models including 14 that had offered standard or optional head air bags by 2004.[27] Of these 14, seven certified to FMVSS 201 with energy-absorbing materials one or more years before they offered head air bags – i.e., they upgraded head impact protection in two separate stages, whereas the other seven certified at the same time or even after they offered head air bags. The analyses identified tangible and relatively substantial additions of energy-absorbing material in five of the seven models that initially certified to FMVSS 201 without head air bags, whereas two certified with minor modification. But when these seven models were subsequently upgraded with head air bags, there were few additional changes in the energy-absorbing materials. Likewise, in the other seven models that initially certified to FMVSS 201 with head air bags, the energy-absorbing materials also changed little at that time.[28] In both groups, the installation of head air bags was generally not accompanied by a substantial upgrade (or downgrade) in the energy-absorbing materials that provide head impact protection.

1.5 What actually happened: average TTI(d), 1981-2002

Background A "typical" NHTSA rulemaking process creates a new performance requirement that is fulfilled in all cars by adding more or less the same specific equipment. All cars have it by the effective date, perhaps a year or two earlier in some cars but in any case after the rulemaking process is underway. The equipment was nonexistent or rare before the rulemaking process started, and it did not change in any important way in the years after the effective date. Center High Mounted Stop Lamps, installed in all 1986 cars and some 1985's, and little changed since then, are a good example of the typical process.[29] In short, we know what happened – and essentially the same thing happened on every make-model – and we know when it happened on each make-model. Evaluation is a relatively straightforward matter of comparing the crashes of vehicles before and after the equipment was installed.

Side structure improvements differ from the typical process in several important respects:

- The dynamic test requirement of FMVSS 214 did not result in the fleet-wide installation of any specific piece of equipment. Different components were modified, depending on the make-model. Furthermore, specific modifications can be difficult to identify if initial FMVSS 214 compliance was "built in" as part of an "integrated platform redesign" of that model.
- Side impact performance is measured by the continuous variables, TTI(d) and pelvic g's. TTI(d) has ranged from 32 to 131 on individual test vehicles. Whereas any TTI(d) up to 85 (90 in a 2-door car) is a "pass" and anything above that is a "fail," there are large differences of performance within the "pass" group and within the "fail" group.

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[27] Ludtke, N.F., Osen, W., Gladstone, R. and Lieberman, W., *Perform Cost and Weight Analysis, Non Air Bag Head Protection Systems, FMVSS 201*, NHTSA Technical Report No. DOT HS 809 810, Washington, 2003; Ludtke, N.F., Osen, W., Gladstone, R. and Lieberman, W, *Perform Cost and Weight Analysis, Head Protection Air Bag Systems, FMVSS 201*, NHTSA Technical Report No. DOT HS 809 842, Washington, 2004.
[28] Ludtke et al. (2004), pp. 3-47 – 3-54; i.e., there were, on the whole, no substantial cost increases (or decreases) in the components that house the energy-absorbing materials.
[29] Kahane, C.J. and Hertz, E., *The Long-Term Effectiveness of Center High Mounted Stop Lamps in Passenger Cars and Light Trucks*, NHTSA Technical Report No. DOT HS 808 696, Washington, 1998.

- TTI(d) began to improve in some make-models well before the FMVSS 214 phase-in. The 1980-1993 development of FMVSS 214 was an iterative process with extensive public participation. Manufacturers could compare TTI(d) in their existing vehicles to levels proposed for FMVSS 214 or achieved by competitors, and correct their worst performers.
- Conversely, if models already had acceptable TTI(d) by MY 1993, manufacturers might certify their 1994 models as FMVSS 214-compliant despite changing nothing, or very little from the 1993's.
- Manufacturers could aim for much better TTI(d) than the 85/90 allowed by FMVSS 214 – upon initial certification, or in subsequent improvements. Side NCAP lets the public know when performance has improved. Subsequent improvements could be the result of adding or redesigning structure and padding, or installing torso and/or head air bags.

In other words, the evaluation of FMVSS 214 is not a simple comparison of two internally homogeneous groups, one "before" and one "after" certification. Side impact protection is a story of ongoing improvement(s), varying from model to model in magnitude and timing. Some models with acceptable performance before 1994 might not have improved much at all. To properly evaluate the effect of side impact protection on a model's fatality risk, we should know its TTI(d) history and identify in what years scores improved and by how much. We should also learn why the scores improved at that time: whether due to structure, padding and/or air bags. That will make it possible to identify groups of make-models that significantly improved side impact protection at specific times and compare their fatality risk before and after the change.

What actually happened *in 1994-1997* The manufacturers provided NHTSA with detailed lists and diagrams showing changes they made to achieve compliance during the phase-in period for FMVSS 214, model years 1994-1997. Structural modifications and padding were the principal technologies used to meet FMVSS 214 in those years. This information suggests that make-models accounting for approximately:

- 56 percent of new car sales received substantial structural modifications, usually accompanied with padding. "Substantial" structure could include extensive strengthening or reinforcement of side door beams; A-, B- or C- pillars; sills; roof rails; seat structures or cross-members of a car: typically 4 or 5 such items per car.
- 21 percent of cars received padding with minor structural modifications. "Minor" structure could include small, localized reinforcements on the components listed above, or even some extensive strengthening, but to at most one or two major components.
- 6 percent of cars received padding only.
- 17 percent remained essentially unchanged from previous years, implying that even the pre-1994 models of these cars could have met FMVSS 214.