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

An Evaluation of Side Structure Improvements in Response to Federal Motor Vehicle Safety Standard 214

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Charles Jesse Kahane, Ph.D.

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An Agency staff review of an existing Federal regulation performed in response to Executive Order 12291.

16. Abstract

Side door beams were installed in passenger cars in response to Federal Motor Vehicle Safety Standard 214. The purpose of beams is to reduce the velocity and depth of door intrusion into the passenger compartment in side impact crashes. The objectives of this Agency staff evaluation are to determine how many fatalities and injuries are prevented by Standard 214, to measure the actual cost of the standard, to assess cost effectiveness and to describe the actual crash performance of equipment installed in response to the standard. The evaluation is based on statistical analyses of the Fatal Accident Reporting System and National Crash Severity Study data, cost analyses of production beam assemblies and a review of staged crash tests. It was found that

o Standard 214 elimina[illegible]30 fatalities and 4,500 nonfatal hospitalizations per year in side impacts with fixed objects. The standard has brought about significantly shallower and wider damage patterns and has reduced occupant ejection in these crashes.

o Standard 214 eliminates 4900 nonfatal hospitalizations per year in vehicle-to-vehicle side impacts but has not reduced fatalities in these crashes. Door intrusion was significantly reduced.

o Standard 214 has added $61 (in 1982 dollars) to the lifetime cost of owning and operating a car.

17. Key Words
side door beam; side impact; angle collision; Federal Motor Vehicle Safety Standard 214; accident analysis; evaluation; statistical analysis; cost effectiveness

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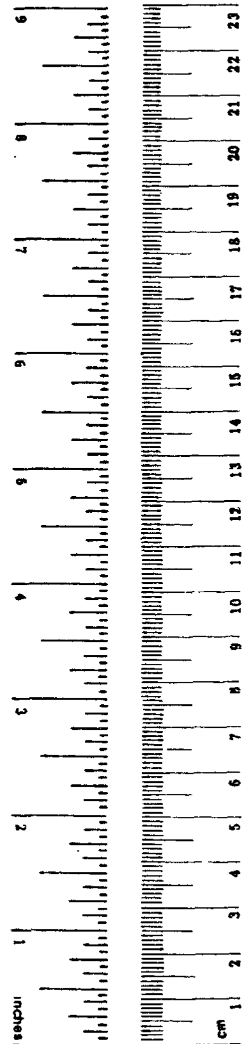
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

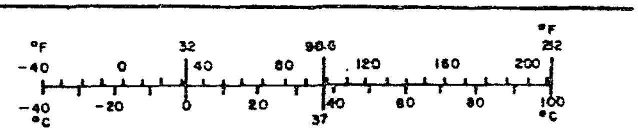
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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*Unpublished computer printouts

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LIST OF ABBREVIATIONS

AIS	Abbreviated Injury Scale
AMC	American Motors Corporation
ANPRM	Advance Notice of Proposed Rulemaking
BMDP	Biomedical programs (P series)
CDC	Collision Deformation Classification
CRASH	Computer Reconstruction of Accident Speeds on the Highway
CY	Calendar Year
df	degrees of freedom
EFU	Equivalent Fatality Unit
FARS	Fatal Accident Reporting System
FMVSS	Federal Motor Vehicle Safety Standard
GM	General Motors
K+A	fatal and serious injuries (police rated)
K+A+B	fatal, serious or visible minor injuries (police rated)
MDAI	Multidisciplianary Accident Investigation
MY	Model Year
NCSS	National Crash Severity Study
NHTSA	National Highway Traffic Safety Administration
NPRM	Notice of Proposed Rulemaking
PDOF	Principal Direction Of Force
SAE	Society of Automotive Engineers
TAD	Traffic Accident Data project accident severity scale
VW	Volkswagen

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Rod Harris, formerly with the Motor Vehicle Manufacturers Association, gathered the most accurate available information on when door beams were installed in passenger cars.

Alleyne Monkman and Michele Stewart typed the report.

EXECUTIVE SUMMARY

Impacts to the side of a passenger car rank second only to frontal crashes as a source of occupant fatalities and serious injuries. They are especially dangerous when the impact is on the passenger compartment because there are no deep, crushable metal structures between the occupant and the impacting vehicle or object, as there are, for instance, in frontal or rear-end crashes. The door collapses into the passenger compartment and the occupants contact the door at a high relative velocity.

During the 1960's, the motor vehicle manufacturers tested various concepts for reducing penetration of the door structure into the passenger compartment. They found that the installation of a horizontal beam inside the door, accompanied by minor reinforcements of other components, significantly reduced side structure intrusion in crash tests. The beams, unlike some of the other concepts, did not change a car's external appearance and posed no problem of customer acceptance. The manufacturers developed a static laboratory test for measuring side door strength. Beams greatly improved a car's test scores. In 1970, the National Highway Traffic Safety Administration issued Federal motor Vehicle Safety Standard 214, which incorporated the static test and required all passenger cars to achieve certain minimum scores on the test, effective January 1, 1973. Beams were installed in all makes and models of cars sold in the United States since the effective date; beams were installed in many models up to 4 years before the effective date.

Executive Order 12291 (February 1981) requires agencies to evaluate their existing major regulations, including any rule whose annual effect on the economy is $100 million or more. The National Highway Traffic Safety Administration published a preliminary evaluation of Standard 214 in 1979, based on analyses of a National Crash Severity Study data file which was less than half complete at that time. Because of the limited accident sample, definitive conclusions could not be reached. A followup evaluation was promised when the data file became complete. That file has been completed and, equally important, additional data sources and new analysis techniques have become available.

This report is the Agency's reevaluation of Standard 214, superseding the findings of the 1979 study. Its evaluation objectives are:

(1) Calculating the benefits specifically due to Standard 214 -- lives saved and injuries prevented or reduced in severity, in side impacts -- after isolating the effect of Standard 214 from the effects of other safety standards or vehicle modifications.

(2) Measuring the cost of components installed or modified in response to Standard 214 in current (1979-82) production vehicles.

(3) Assessing cost-effectiveness.

(4) Comparing the effectiveness of Standard 214 in single and multivehicle crashes; for nearside and farside occupants; for impacts centered on the passenger compartment vs. other side impacts; for mitigating various specific types and sources of injury.

(5) Describing the effect of Standard 214 on side structure performance in highway accidents, based on analyses of vehicle damage patterns.

(6) Providing a physical explanation of why Standard 214 does (or does not) eliminate certain specific types of injuries in specific types of side impacts.

(7) Comparing the mechanisms whereby Standard 214 reduces casualties in highway accidents to the stated rationale for the standard and to hypotheses, based on staged crashes and engineering analyses, about how the standard works.

The fatality reduction due to Standard 214 was accurately estimated by analyzing 7 years of Fatal Accident Reporting System (FARS) data. Statistical analyses of National Crash Severity Study (NCSS) data were performed to determine the number of serious injuries prevented. Nonserious injury reduction was measured from 3 years of Texas accident files. All effectiveness analyses were limited to, or emphasized, cars built just before and just after the installation of beams -- in order to isolate the casualty reduction that is specifically due to Standard 214 and to exclude reductions due to other safety standards (201, 203, 204, 205, 206, 208-210, 216) and vehicle modifications (the shift from genuine to pillared hardtops, etc.), which took place some years before or after beam installation. Multivariate statistical techniques were also used to accomplish this goal.

The analyses of the effect of Standard 214 on vehicle damage patterns and on specific types of injuries are primarily based on NCSS, supplemented, where possible, with FARS results. The cost of Standard 214 was calculated by analyzing the individual components of a representative sample of current (1979-82) cars, updating the cost estimates of the preliminary evaluation.

Engineering studies of the side impact problem and staged side impact crashes were thoroughly reviewed and discussed with Agency engineers. The review made it possible to formulate 5 specific hypotheses on how Standard 214 affects the performance of the side structure in crashes. The analyses of vehicle damage patterns and specific injury types were geared to testing these hypotheses and, finally, developing a physical explanation for the effectiveness of Standard 214 (or lack thereof) in various types of side impacts.

The most important conclusions of this evaluation are that Standard 214 has saved 480 lives per year and has significantly reduced serious injuries in side impacts with fixed objects. Standard 214 has significantly reduced serious injuries, but has had little or no effect on fatalities, in vehicle-to-vehicle side impacts -- moreover, the reduction in multivehicle crashes is primarily limited to impacts that are centered on the passenger compartment and to occupants seated adjacent to the struck side of the car. The detailed analyses of vehicle damage patterns and specific injury types established physical explanations for the effects of Standard 214 that are in complete agreement with these conclusions.

The principal findings and conclusions of the study are the following:

Principal Findings

The problem

o In 1980, when 75 percent of the passenger cars on the highway were in compliance with Standard 214, 7800 passenger car occupants were killed in side impact crashes. There would have been 8200 fatalities if the side structure improvements required by Standard 214 had not been made (confidence bounds: 8050 to 8350); 3400 of the fatalities would have occurred in single-vehicle crashes; 4800 in multivehicle crashes.

o There would have been 74,000 fatalities and hospitalizations in side impact crashes in 1980 if Standard 214 had not been promulgated (confidence bounds: 67,000 to 80,000).

o The distribution of the serious casualties (fatalities and hospitalizations) by crash type, occupant seat location and damage location would have been:

	Fatalities and Hospitalizations in			
	Single-Vehicle Crashes		Multivehicle Crashes	
	N	Percent	N	Percent
Nearside occupants - damage centered on compartment	7,200	36	20,000	37
Nearside occupants - damage not centered on compartment	3,400	17	11,000	20
Farside occupants	9,400	47	23,000	43
TOTAL	20,000		54,000	

o The distribution of injury sources among pre-Standard 214 occupant fatalities and hospitalizations was:

		Percent of Serious Injuries	
Contacts with side interior surfaces (doors, pillars, etc.)	49		
Head injuries (including face and neck)		14	
Rest of body		35	
Nearside occ. in multiveh. compartment impacts			17
All other persons			18
Contacts with front interior components (dashboard, etc.)		30	
Objects exterior to vehicles (mostly ejections)		8	
Other		13	

Fatality reduction for Standard 214

o Standard 214 reduced the risk of occupant fatality in single-vehicle side impacts by 14 percent (confidence bounds: 7 to 21 percent).

o In the preceding estimate, the definition of "single-vehicle side impact" included grade crossing accidents, rollovers with primarily side damage and complex off-road excursions. If the definition is restricted to side impacts with fixed objects, the effectiveness rises to 23 percent.

o Standard 214 had no observed effect on multivehicle crash fatalities (confidence bounds: -9 to +7 percent).

Serious casualty reduction for Standard 214

o Standard 214 reduced the risk of occupant fatality or hospitalization in side impacts, as follows:

	Serious Casualty Reduction (%)	Confidence Bounds
In single-vehicle crashes	25	11 to 35
In multivehicle crashes:		
Nearside occupants in compartment impacts	25	6 to 38
All occ. in all multivehicle crashes	8	-3 to 17

Nonserious injury reduction for Standard 214

o Standard 214 reduced drivers' risk of police-reported "visible minor" (level B) injuries, in side impacts, in Texas, as follows:

	"Visible Minor" Injury Reduction (%)	Confidence Bounds
In single-vehicle crashes	9	-1 to 19
In multivehicle crashes	13	8 to 18

Effect of Standard 214 on depth and width of crush

o In single-vehicle crashes the depth of crush decreased by an average of 20 percent while the width of the damaged area increased by 20 percent. In other words, Standard 214 resulted in significantly shallower and wider damage patterns.

o In multivehicle crashes centered on the compartment, the depth of crush decreased by an average of 20 percent while the width of the damaged area was unaffected. Standard 214 significantly reduced penetration without otherwise affecting the shape of the damage pattern.

o Standard 214 had no observed effect on crush patterns in multivehicle impacts that were not centered on the compartment.

Effect on location of the damaged area

o The percentage of cars in which damage was centered on the compartment was:

	Percent of Cars with Damage Centered on Compartment:	
	In Single-Vehicle Crashes	In Multivehicle Crashes
Last 5 model years before Standard Standard 214	50	31
First 5 model years after Standard 214	38	32

Effect on the performance of doors in crashes

o Standard 214 affected the performance of doors in side impact crashes, as follows:

	Observed Effect of Standard 214 (%)	
	In Single-Vehicle Crashes	In Multivehicle Crashes
Reduction of occupant ejection through doors	40-60	10-50
Reduced incidence of doors opening in crashes	20-40	10-30
Reduced incidence of latch or hinge damage	10-20	0-5

Effect on sill override

o Standard 214 reduced the incidence of sill override in multi-vehicle crashes by about 20 percent.

Effectiveness of Standard 214 - by injury source

o In collisions with fixed objects, Standard 214 reduced ejection fatalities by 24 percent and nonejection fatalities by 22 percent. Both reductions are statistically significant.

o The reduction of serious injuries (resulting in fatality or hospitalization), by injury type, was:

	Observed Reduction for Standard 214 (%)	
	In Single-Vehicle Crashes	In Multivehicle Crashes
Contacts with side interior surfaces (doors, etc.)	36	10
Head injuries (incl. face and neck)	25	1
Rest of body	41	14
Nearside occ. in compartment impacts	50	33
All other persons	23	-10
Contacts with front interior components (steering assembly, etc.)	27	0
Objects exterior to vehicles (mostly ejections)	63	57

Benefits of Standard 214

o The annual benefits of Standard 214, when all cars on the road meet the standard, will be:

	Best Estimate	Confidence Bounds
LIVES SAVED -- in single vehicle crashes	480	300 to 660
NONFATAL HOSPITALIZATIONS ELIMINATED		
In single vehicle crashes	4,550	900 to 8,200
In multivehicle crashes	4,920	800 to 9,000
TOTAL	9,470	4,300 to 14,700
"VISIBLE MINOR" (LEVEL B) INJURIES ELIMINATED -- Multivehicle	15,000	-------

Cost of Standard 214

o Standard 214 added an average of $30 (in 1982 dollars) to the purchase price of current (1979-82) cars.

o It increased the weight of a car by 28 pounds.

o The total lifetime cost of Standard 214 (including fuel consumption due to the weight increase) is $61 per car (in 1982 dollars).

Cost-effectiveness

o An "Equivalent Fatality Unit" corresponds to 1 fatality or 16.9 nonfatal hospitalizations. Standard 214 eliminates 1.7 Equivalent Fatality Units per million dollars of cost (confidence bounds: 1.1 to 2.3).

Conclusions

Single-vehicle side impacts

o Standard 214 has significantly reduced fatalities and serious injuries in single vehicle crashes.

o The standard has helped cars "glance by" fixed objects, limiting the damage in the compartment area and spreading it to less vulnerable regions of the car. It has reduced the overall severity of the collision, not only for persons sitting next to the damaged area but also, to a lesser extent, for the other occupants.

o It has thereby also helped protect the integrity of the door structure, significantly reducing the risk of occupant ejection, even in potentially fatal crashes.

o The standard has accomplished the goal of reducing nearside occupants' torso, arm and leg injuries due to contact with the car's side structure.

o But the standard's benefits also extend to head injuries, contacts other than the side structure, and farside occupants, because it has made crashes generally less severe and it has reduced ejection. For these reasons, it has significantly reduced fatalities as well as nonfatal serious injuries.

Multivehicle side impacts

o Standard 214 has significantly reduced nonfatal serious injuries and nonserious injuries in multivehicle crashes.

- It has had little or no effect on fatalities.

- The standard has reduced side structure intrusion when the car is directly impacted in the compartment by another vehicle. The reduction is primarily a consequence of increased crush resistance.

- It does not appear to significantly promote deflection of the striking vehicle -- the effect that was prominently displayed in fixed object collisions.

- The standard may have been partially effective in preventing the striking vehicle from overriding the sill. This effect, at best, accounts for only a small portion of the standard's benefit in multi-vehicle crashes.

- The standard may have reduced occupant ejection -- a mechanism that accounts for a much smaller percentage of the injuries in multi-vehicle than in single vehicle crashes.

- The standard has accomplished its goal of significantly reducing nearside occupants' torso, arm and leg injuries due to contact with side structures in compartment impacts. These lesions constitute a large portion of the serious nonfatal injuries but a much smaller portion of the fatalities.

- But the standard appears to have had negligible effect on all other types of injuries (except, possibly, ejections).

- The standard has had negligible effect on fatalities, primarily, because it has not significantly reduced head injuries and also, perhaps, because the added crush resistance in the doors, without other major modifications, is of little use in extremely severe crashes.

o Although Standard 214 has had significant benefits in multivehicle crashes, they are exceeded by the benefits in single vehicle crashes.

CHAPTER 1

INTRODUCTION

1.1 Federal Motor Vehicle Safety Standards -- the program and its evaluation

The primary goal of the National Highway Traffic Safety Administration is to reduce deaths, injuries and damages resulting from motor vehicle accidents. The Federal Motor Vehicle Safety Standards are one of NHTSA's principal safety programs. Each standard requires certain types of new motor vehicles or motor vehicle equipment sold in the United States to meet specified safety performance levels. Over 50 standards, affecting cars, trucks, buses, motorcycles or aftermarket parts, have been issued since 1966.

The National Traffic and Motor Vehicle Safety Act of 1966 [61], which provides the authority to issue safety standards, specifies that each standard shall be "practicable," "meet the need for motor vehicle safety" and "provide objective criteria." It defines "motor vehicle safety" to mean protection against "unreasonable" risk of accidents, deaths or injuries.

The Federal Motor Vehicle Safety Standards set minimum performance requirements. Manufacturers may choose any design that meets or, for that matter, exceeds the minimum requirements. They may provide additional safety equipment which generally mitigates the highway safety problem addressed by the standard but is not actually needed to meet the specific compliance test requirements.

The Government, the motor vehicle manufacturers and independent researchers have contributed to the development of motor vehicle standards. In the case of the early (1968-69) standards especially, it was the motor vehicle industry that conducted or sponsored much of the research and sought self-regulation through the Society of Automotive Engineers' Recommended Practices. The Government subsequently promulgated performance requirements that many vehicles were already meeting or exceeding.

In 1975, NHTSA began to evaluate existing Federal Motor Vehicle Safety Standards [50]. The specific objectives of each evaluation were:

(1) To determine if a standard was actually performing as intended.

(2) To determine benefits and costs.

Since 1975, the Agency has received a number of directives to continue reviewing its existing standards. In mid-1982, the legislation and orders governing the review are:

Executive Order 12291, dated February 17, 1981, requires agencies to initiate reviews of existing regulations and perform Regulatory Impact Analyses of existing major rules [27]. "Major" rules include, among others, those which result in an annual effect on the economy of $100 million or more. The Regulatory Impact Analysis shall determine the actual costs and actual benefits of the existing rule and the potential costs and benefits of viable alternatives to the current rule, if any exist. The Analysis must test whether: (1) The benefits to society of the existing rule outweigh the costs. (2) The net benefits of the existing rule exceed the net benefits of the potentially viable alternatives. (3) The rule, in combination with the Agency's other regulations, maximizes the aggregate net benefits to society taking into account the condition of the particular industries affected by regulations, the condition of the national economy, and other regulatory actions contemplated for the future.

Department of Transportation Order 2100.5 is dated May 22, 1980, and titled "Policies and Procedures for Simplification, Analysis and Review of Regulations" [64]. The Department publishes a "Semiannual Review List" that shows which evaluations of existing regulations are in progress or planned and their target completion dates [28]. It identifies those existing regulations scheduled for priority review.

The Regulatory Flexibility Act of 1980 requires that evaluations of existing regulations also consider their economic impact and administrative burden on small businesses [69]. Most safety standards, however, primarily affect the major manufacturers and have little or no impact on small businesses.

The Agency published a report titled "Regulatory Reform -- The Review Process" for public comment in March 1982 [70]. The report described the objectives, policies, accomplishments and plans for the Agency's evaluation program.

The first evaluation published by the Agency was a preliminary "Evaluation of Standard 214" -- Side Door Strength [46], which appeared in September 1979 and assessed the actual costs and actual benefits of Standard 214 and measured cost-effectiveness. This report is a reevaluation of the same standard and its findings supersede the contents of the preliminary evaluation.

1.2 What is Standard 214?

Federal Motor Vehicle Safety Standard 214, which became effective for passenger cars manufactured after January 1, 1973, established static crush resistance requirements for side doors. Its stated objective was to protect occupants from the hazard of side structures collapsing inward on them in side impact collisions.

Standard 214 has led to the installation of horizontal beams within the doors of all passenger cars. The installation of beams was the major vehicle modification performed in response to Standard 214. There is no record of any production vehicle to date (1982) that had beams and was unable to meet the standard, nor of any without beams that met the standard.

The side door beam and the static crush resistance test for doors were developed at the Fisher Body Division of General Motors, under the leadership of Carl Hedeen and David D. Campbell. The beams were installed in all full-sized 1969 model GM cars, over 4 years before the standard's effective date. Ford, Chrysler and American Motors also provided beams in many of their cars before January 1, 1973. In this evaluation, cars equipped with beams are treated as "post-Standard 214 vehicles" even if they were produced before the standard's effective date.

1.3 Why reevaluate Standard 214?

NHTSA's preliminary evaluation of Standard 214, published in 1979, was based on a National Crash Severity Study data file which was less than half complete at that time. Because of the limited accident sample, the statistical results were subject to considerable error and conclusions could not be definitively stated. It was also impossible to perform the type of in-depth analyses that would establish why Standard 214 was effective or not effective. For these reasons, the preliminary evaluation contained a promise that a followup would be performed when the NCSS file was completed ([46], p. xviii). A complete NCSS became available in November 1980.

Moreover, in the 1981 evaluation of energy-absorbing steering assemblies [44], NHTSA developed analysis techniques that permit more precise and unbiased statistical results to be obtained from NCSS data. The new techniques are applied, in this evaluation, to the study of side impacts.

The Fatal Accident Reporting System, with analysis techniques developed in the steering assembly evaluation and the 1982 evaluation of head restraints [45], has become a powerful tool for estimating a standard's fatality reduction, independent of the injury reduction. FARS is used in this report to estimate the number of lives saved by Standard 214, superseding the NCSS-based estimates of fatality reduction in the preliminary report. Also, in this evaluation, NCSS results on injury reduction are supplemented by estimates based on Texas accident data, derived by analysis techniques used in the head restraint evaluation.

The literature on side impact research and crash testing was thoroughly reviewed before the preparation of this report. The review provided valuable insights on how beams may be hypothesized to perform in crashes and it served as a guide for the analyses of crash damage and injury data to test the hypotheses.

Comments on the preliminary report raised questions whether some of the benefits attributed to Standard 214 might, in fact, be due to other vehicle modifications or possible biases in the data [2]. With the larger sample and improved analysis techniques available for this report, it was possible to pay much greater attention to controlling for or eliminating the effects of other safety devices or biases in the data.

Cost and weight data were obtained on a substantial number of cars produced after 1973, making it possible to update the cost estimate for Standard 214.

1.4 Contents of the evaluation

Chapter 2 describes the principal findings and conclusions of the evaluation. It also summarizes why Standard 214 has been effective and assesses the strengths and weaknesses of the analyses.

Chapter 3 surveys the safety problem addressed by Standard 214. It describes the number, severity and mechanisms of passenger car occupant casualties in side impact crashes.

Chapter 4 reviews the development of Standard 214. It contains an engineering-oriented discussion of how beams are likely to perform in accidents and a review of staged crash test results. It describes vehicle modifications other than Standard 214 which may affect injury risk in side impacts.

Chapter 5 reviews published statistical analyses of Standard 214.

Chapters 6, 7 and 8 estimate the overall effectiveness of Standard 214 in single vehicle and multivehicle side impacts: Chapter 6 estimates the fatality reduction from FARS data; Chapter 7, serious injury reduction from NCSS; Chapter 8, nonserious injury reduction in Texas.

Chapters 9 and 10 investigate why Standard 214 has been effective: Chapter 9, based on analysis of vehicle damage patterns in NCSS; Chapter 10, based on detailed injury data.

Chapter 11 assesses the actual cost of Standard 214 in production vehicles and the actual benefits in highway accidents.

CHAPTER 2

FINDINGS AND CONCLUSIONS

The results from the evaluation of Standard 214 (Side Door Strength -- Passenger Cars) are presented in this chapter. The findings are based on statistical analyses of the National Crash Severity Study (NCSS), the Fatal Accident Reporting System (FARS) and Texas accident files for 1972, 1974 and 1977; a component cost analysis of a representative sample of vehicles; a review of the literature on side impact research and crash test results; and discussion with engineers about research in side impact protection.

2.1 Principal statistical findings

The problem

o In 1980, when 75 percent of the passenger cars on the highway were in compliance with Standard 214, 7800 passenger car occupants were killed in side impact crashes. There would have been 8200 fatalities if the side structure improvements required by Standard 214 had not been made (confidence bounds: 8050 to 8350).

o The distribution of the fatalities, by crash type and occupant seat location (relative to the side of the car that was damaged) would have been:

	Fatalities in			
	Single-Vehicle Crashes		Multivehicle Crashes	
	N	Percent	N	Percent
Nearside occupants	2000	58	3300	69
Farside occupants	1400	42	1500	31
TOTAL	3400		4800	

o There would have been 74,000 fatalities and hospitalizations in side impact crashes in 1980 if Standard 214 had not been promulgated (confidence bounds: 67,000 to 80,000).

o The distribution of the serious casualties (fatalities and hospitalizations) by crash type, occupant seat location and damage location would have been:

	Fatalities and Hospitalizations in			
	Single-Vehicle Crashes		Multivehicle Crashes	
	N	Percent	N	Percent
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Nearside occupants - damage not centered on compartment	3,400	17	11,000	20
Farside occupants	9,400	47	23,000	43
TOTAL	20,000		54,000	

o The distribution of injury sources among pre-Standard 214 occupant fatalities and hospitalizations was:

	Percent of Serious Injuries		
Contacts with side interior surfaces (doors, pillars, etc.)	49		
Head injuries (including face and neck)		14	
Rest of body		35	
Nearside occ. in multiveh. compartment impacts			17
All other persons			18
Contacts with front interior components (dashboard, etc.)		30	
Objects exterior to vehicles (mostly ejections)		8	
Other		13	

Fatality reduction for Standard 214

o Standard 214 reduced the risk of occupant fatality in single-vehicle side impacts by 14 percent (confidence bounds: 7 to 21 percent).

o In the preceding estimate, the definition of "single-vehicle side impact" included grade crossing accidents, rollovers with primarily side damage and complex off-road excursions. If the definition is restricted to side impacts with fixed objects, the effectiveness rises to 23 percent.

o Standard 214 had no observed effect on multivehicle crash fatalities (confidence bounds: -9 to +7 percent).

Serious casualty reduction for Standard 214

o Standard 214 reduced the risk of occupant fatality or hospitalization in side impacts, as follows:

	Serious Casualty Reduction (%)	Confidence Bounds
In single-vehicle crashes	25	11 to 35
In multivehicle crashes:		
Nearside occupants in compartment impacts	25	6 to 38
All occ. in all multivehicle crashes	8	-3 to 17

Nonserious injury reduction for Standard 214

o Standard 214 reduced drivers' risk of police-reported "visible minor" (level B) injuries, in side impacts, in Texas, as follows:

	"Visible Minor" Injury Reduction (%)	Confidence Bounds
In single-vehicle crashes	9	-1 to 19
In multivehicle crashes	13	8 to 18

Effect of Standard 214 on depth and width of crush

o In single-vehicle crashes the depth of crush decreased by an average of 20 percent while the width of the damaged area increased by 20 percent. In other words, Standard 214 resulted in significantly shallower and wider damage patterns.

o In multivehicle crashes centered on the compartment, the depth of crush decreased by an average of 20 percent while the width of the damaged area was unaffected. Standard 214 significantly reduced penetration without otherwise affecting the shape of the damage pattern.

o Standard 214 had no observed effect on crush patterns in multivehicle impacts that were not centered on the compartment.

Effect on location of the damaged area

o The percentage of cars in which damage was centered on the compartment was:

	Percent of Cars with Damage Centered on Compartment:	
	In Single-Vehicle Crashes	In Multivehicle Crashes
Last 5 model years before Standard Standard 214	50	31
First 5 model years after Standard 214	38	32

Effect on the performance of doors in crashes

o Standard 214 affected the performance of doors in side impact crashes, as follows:

	Observed Effect of Standard 214 (%)	
	In Single-Vehicle Crashes	In Multivehicle Crashes
Reduction of occupant ejection through doors	40-60	10-50
Reduced incidence of doors opening in crashes	20-40	10-30
Reduced incidence of latch or hinge damage	10-20	0-5

Effect on sill override

o Standard 214 reduced the incidence of sill override in multi-vehicle crashes by about 20 percent.

Effectiveness of Standard 214 - by injury source

o In collisions with fixed objects, Standard 214 reduced ejection fatalities by 24 percent and nonejection fatalities by 22 percent. Both reductions are statistically significant.

o The reduction of serious injuries (resulting in fatality or hospitalization), by injury type, was:

	Observed Reduction for Standard 214 (%)	
	In Single-Vehicle Crashes	In Multivehicle Crashes
Contacts with side interior surfaces (doors, etc.)	36	10
Head injuries (incl. face and neck)	25	1
Rest of body	41	14
Nearside occ. in compartment impacts	50	33
All other persons	23	-10
Contacts with front interior components (steering assembly, etc.)	27	0
Objects exterior to vehicles (mostly ejections)	63	57

Benefits of Standard 214

o The annual benefits of Standard 214, when all cars on the road meet the standard, will be:

	Best Estimate	Confidence Bounds
LIVES SAVED -- in single vehicle crashes	480	300 to 660
NONFATAL HOSPITALIZATIONS ELIMINATED		
In single vehicle crashes	4,550	900 to 8,200
In multivehicle crashes	4,920	800 to 9,000
TOTAL	9,470	4,300 to 14,700
"VISIBLE MINOR" (LEVEL B) INJURIES ELIMINATED -- Multivehicle	15,000	-------

Cost of Standard 214

o Standard 214 added an average of $30 (in 1982 dollars) to the purchase price of current (1979-82) cars.

o It increased the weight of a car by 28 pounds.

o The total lifetime cost of Standard 214 (including fuel consumption due to the weight increase) is $61 per car (in 1982 dollars).

Cost-effectiveness

o An "Equivalent Fatality Unit" corresponds to 1 fatality or 16.9 nonfatal hospitalizations. Standard 214 eliminates 1.7 Equivalent Fatality Units per million dollars of cost (confidence bounds: 1.1 to 2.3).

2.2 The side impact safety problem

Standard 214 was promulgated in order to strengthen the doors of passenger cars and to protect occupants in side impact crashes. Side impacts are hazardous, especially when the impact is on the passenger compartment, because there is relatively little energy-absorbing "metal" between the occupants and the point of contact.

The specific source of injury most frequently described in the literature involves a nearside occupant's torso, arms or legs contacting the car's intruding side structure while it is being struck in the passenger compartment by another motor vehicle. The side structure offers relatively little resistance to the striking vehicle and the occupant contacts the door structure before the striking vehicle has been appreciably decelerated. A "nearside" occupant is one sitting adjacent to the side of the car that was struck. A "compartment" impact is one that was centered on the compartment; throughout this evaluation it is defined to be an impact in which the midpoint of the damaged area is no more than 45 inches to the front or 15 inches to the rear of the midpoint of the car. This definition is more restrictive than what has been used in earlier reports but is necessary to exclude collisions which only peripherally damage the compartment and in which side structure intrusion is unimportant.

But there are other important injury mechanisms. In severe crashes, serious torso injury can occur from contact with the side structure even when high speed intrusion is not a severity-increasing factor (e.g., farside occupants). Head injuries due to contact with the upper parts of the side structure are common, especially as a source of fatal injuries.

Occupant ejection is a major problem in single-vehicle side impacts. Many injuries occur due to contact with frontal components of the car (dashboard, windshield, etc.). (See Section 3.2.1 for a discussion of injury mechanisms.)

The starting point for the evaluation is, then, to determine how many deaths and serious injuries there would have been in the United States during the base year - 1980 - in passenger cars struck in the side, if Standard 214 had not been promulgated (but the accident environment was otherwise the same as in 1980). Table 2-1 shows that 73,600 passenger car occupants would have been killed or hospitalized (at least overnight) in side impacts in 1980 if Standard 214 had not been promulgated (confidence bounds: 67,300-80,000, one-sided = .05); 8170 of these casualties would have been fatalities (confidence bounds: 8020 to 8320). The estimate of fatalities and hospitalizations is derived from the National Crash Severity Study (NCSS); the estimate of fatalities, from the Fatal Accident Reporting System (FARS) -- see Sections 3.1 and 11.2. (The estimates are the sum of the actual number of casualties in 1980 and the number that Standard 214 eliminated in that year.)

There are two fundamental types of side impacts: those occurring in single vehicle crashes (mostly collisions involving a skid into a fixed object such as a pole or tree) and multivehicle crashes (where, most often, a car is hit in the side by another car or a light truck). Throughout the remainder of this evaluation, the two types of crashes are always analyzed separately, because they involve a different mix of injury mechanisms and, above all, because Standard 214 appears to work differently in the two crash types. Table 2-1 shows that 20,100 of the fatalities and hospitalizations occurred in single-vehicle crashes (confidence bounds: 16,400-23,800), including 3360 fatalities (confidence bounds: 3210-3510).

TABLE 2-1

BASELINE CASUALTIES IN 1980 SIDE IMPACTS

(If Standard 214 had not been promulgated)

	Fatalities[1] N	Fatalities[1] % Subtotal	Fatalities and Hospitalizations[2] N	Fatalities and Hospitalizations[2] % of Subtotal
In single-vehicle crashes	3360		20,100	
Nearside occ.-damage centered on compartment	1950	58	7,200	36
Nearside occ.-not centered on compartment			3,400	17
Farside occupants	1410	42	9,400	47
In multivehicle crashes	4810		53,500	
Nearside occ.-damage centered on compartment	3320	69	19,700	37
Nearside occ.-not centered on compartment			10,700	20
Farside occupants	1490	31	23,100	43
TOTAL	8170		73,600	

[1]Estimates based on FARS

[2]Estimates based on NCSS

Two other fundamental classifiers of persons involved in side impacts are occupant location relative to the damaged area (nearside vs. farside) and the location of the damaged area (centered on the passenger compartment vs. not centered). Table 2-1 shows that farside occupants and nearside occupants in noncompartment crashes together account for a majority of side impact hospitalizations. It shows that, in multivehicle crashes, nearside occupants in compartment impacts account for 19,700 fatalities and hospitalizations (confidence bounds: 15,800-23,600), which is 37 percent of the serious casualties. These are the persons most exposed to contact with rapidly intruding side structures.

Table 2-2 shows the relative frequency of specific injury sources. Objects on the interior side surface of the car (the doors, pillars, armrests, side windows, etc.) account for 49 percent of the injuries resulting in death or hospitalization. However, only a third of these (17 percent of all serious injuries) can be realistically attributed to contacts with rapidly intruding side surfaces: the torso, arm and leg injuries of nearside occupants in multivehicle compartment crashes. Farside occupants, single vehicle crashes and noncompartment impacts, together, produced an equally large proportion of the side surface torso injuries. Head injuries due to side surface contact account for 14 percent of serious injuries and, according to Table 3-6, 26 percent of fatal lesions. A major portion of side impact injuries (30 percent) involve contact with frontal components (steering assembly, dashboard, etc.). Exterior objects (mostly contacted as a result of occupant ejection) accounted for 5 percent of the serious injuries in multivehicle crashes, 16 percent in single vehicle crashes and, according to Table 3-6, 29 percent of fatalities.

TABLE 2-2

SERIOUS INJURY SOURCES IN PRE-STANDARD 214 SIDE IMPACTS

	Percent of Serious* Injuries		
	In Single-Vehicle Crashes	In Multi-Vehicle Crashes	In All Side Impacts
Contacts with side interior surfaces (doors, pillars, etc.)	42	52	49
Head injuries (including face and neck)	15	13	14
Rest of body	27	39	35
Nearside occ. in multiveh. compartment impacts	--	24	17
All other persons	27	15	18
Contacts with front interior components (steering assembly, dashbord, etc.)	34	28	30
Objects exterior to vehicle (mostly ejection)	16	5	8
Other	8	14	13

*Resulting in fatality or hospitalization

In other words, torso injuries due to contact with intruding side structures in multivehicle crashes are the largest single cause of serious nonfatal injuries, but they appear to be superseded, as causes of death by head injuries due to side surface contact and by ejection. (See Section 3.3 for additional discussion.)

2.3 Effectiveness of Standard 214

The Fisher Body Division of General Motors developed and crash-tested modified side structures during the 1960's. They found that a side door beam, accompanied by local reinforcement of the B pillar at the floor level, significantly reduced side structure intrusion in crash tests. It also helped partially deflect the striking vehicle in oblique crashes and reduced the tendency of the striking vehicle to override the sill of the struck car. They also developed a static crush test to measure the increase in door strength gained by installing beams. The National Highway Traffic Safety Administration promulgated Standard 214, which contains crush resistance requirements based on this static test. Manufacturers responded to the standard by installing beams in all cars, model by model, during 1969-1973. The beam was the major vehicle modification performed in response to Standard 214. Except for minor reinforcements of pillars or, possibly, other supporting structures, there is no evidence that other modifications to structures or padding were performed to obtain Standard 214 compliance or as an accompaniment to beam installation. Moreover, with a few minor exceptions, no other safety standard or important side structure modification was implemented within 2 model years before or after the installation of beams. (See Sections 4.2 and 4.4 for more detail.)

The effectiveness of Standard 214 is determined by first calculating occupants' risk of death or injury in side impacts of pre-Standard 214 cars -- i.e., cars not equipped with beams. The corresponding risk is calculated for beam-equipped cars. The difference in injury risk, to the extent that it is due to Standard 214, is the effectiveness.

2.3.1 Fatality reduction

Fatality-reducing effectiveness was estimated using Fatal Accident Reporting System (FARS) data files for 1975-81. Since FARS does not contain information on nonfatal crashes, it is not possible to directly calculate the fatality risk (the number of deaths per 100 crash-involved occupants). Instead, the reduction in fatality risk attributable to Standard 214 is indirectly obtained by comparing side impact fatalities in cars of the first model year with beams and in comparable cars of the last model year without beams to frontal impact fatalities in the same makes and models:

FATALITIES	frontal impacts	side impacts
last model year without beams	n_{11}	n_{12}
first model year with beams	n_{21}	n_{22}

$$\text{Effectiveness of Std. 214} = 1 - \frac{n_{22}\, n_{11}}{n_{21}\, n_{12}}$$

(See Section 6.1 for general discussion of the analysis and 6.2 for data definitions.)

First, the comparison was performed using side impact and frontal impact fatalities in single vehicle crashes. Standard 214 reduced side impact fatalities by a statistically significant 13 percent. In multi-vehicle crashes, however, side impact fatalities increased in post-standard cars by a nonsignificant 6 percent (see Section 6.3.1).

The results were checked by extending the data to include cars of the first two model years with beams and the last two years without them. With this extended sample, the effectiveness of Standard 214 in single-vehicle crashes was 14 percent, nearly the same as in the 1 year comparison, and a statistically significant reduction. Moreover, the observed effectiveness in single vehicle crashes was almost equally large for nearside occupants (14%) and farside occupants (15%) -- both of which are significant reductions. These results indicate that the benefits of Standard 214 are not limited to nearside occupants in single vehicle crashes (see Section 6.3.2).

Confidence bounds for the reduction in single vehicle crashes were obtained by an empirical procedure: the 7 years of FARS data were construed as independent subsamples. Effectiveness was calculated separately for each year of FARS, and based on the variation among the subsamples, the confidence bounds for effectiveness in single vehicle crashes were 7 to 21 percent (see Section 6.3.3).

In the 2 year comparison of multivehicle crashes, however, side impact fatalities again increased by 6 percent in the post-standard cars. Because the sample is larger than in the previous comparison, this is now a significant increase. Did Standard 214 increase fatalities or is there a bias in the analysis? For that matter, could there have been a bias in the analysis of single vehicle crashes?

In order to check for biases in the preceding analysis, another technique was used. Frontal and side impact fatalities were tabulated by model year (1967-75) and calendar year (1975-81) and regressions were performed on the proportion of fatalities that were in side impacts, as a function of Standard 214 status and vehicle age. The regressions attributed to Standard 214 a 13 percent fatality reduction in single vehicle crashes -- the reduction is statistically significant and nearly identical to earlier results. In multivehicle crashes, they attributed to Standard 214 a 4 percent increase in fatalities -- the increase is nonsignificant and not as large as the earlier results (see Section 6.4).

As an additional check, the frontal impact control group was discarded and side impact fatality rates were calculated per 1000 vehicle exposure years (using FARS fatality counts and vehicle registration data). Regressions were performed on these fatality rates, as a function of Standard 214 status and vehicle age. These regressions attributed to Standard 214 a significant 14 percent fatality reduction in single vehicle crashes. In multivehicle crashes, they attributed no effect in either direction (i.e., less than ½ percent) to Standard 214. This regression suggests that the use of a frontal impact control group may have caused a slight bias against the standard (in multivehicle crashes only) in the preceding analysis and that the actual effect of the standard is close to zero (confidence bounds: -9 to +7 percent; see Section 6.6).

In summary, the 4 analyses for single vehicle crashes produced 2 estimates of 14 percent fatality reduction and 2 estimates of 13 percent -- i.e., nearly the same result each time. Since the 2 year comparison using the frontal impact control group was the most precise one, it is used as the "best" estimate of fatality reduction in single vehicle side impacts -- viz., 14 percent. In the 4 analyses for <u>multivehicle</u> crashes, the regression on fatality rates per 1000 vehicle years appears to have eliminated some biases that were due to the frontal impact control group; it is accepted as the "best" estimate of fatality reduction -- viz., no effect for Standard 214. (see Section 6.7.)

In the definition of "single vehicle side impact" used with FARS, about a third of the fatalities were collisions with trains, rollovers with primary damage to the side of the car, complex off-road excursions or collisions with moveable objects. Standard 214 was not effective in any of these crash types.

When these fatalities are excluded and the analysis is limited to collisions with <u>fixed objects</u> (poles, trees, walls, buildings, guard rails), the effectiveness of Standard 214 rose to <u>23 percent</u> (see Section 10.4.1).

2.3.2 <u>Serious injury reduction</u>

The National Crash Severity Study (NCSS) was used to obtain estimates of serious injury reduction. For this evaluation, a person was "seriously injured" if killed or if transported from the accident scene and hospitalized (at least) overnight. (Table 2-1 showed that, by this definition, 89 percent of the serious casualties are nonfatal and 11 percent are fatalities.) This injury criterion, which was also used in NHTSA's evaluation of the steering column [44], is easily understood and also highly advantageous, from a statistical point of view, in connection with the NCSS sampling plan.

The NCSS file contains 404 persons who were killed or hospitalized in single-vehicle side impacts and 1188 in multivehicle side impacts; 385 of the latter were nearside occupants in crashes centered on the compartment. These casualties are divided fairly evenly between pre- and post-standard cars. In short, the samples are large enough to apply statistical modelling techniques in a meaningful way and to discard cars produced long before or after the standard's effective date (sources of bias in the injury rates). (See Section 7.1.1-7.1.3 for definitions and Section 7.3 for raw data tabulations.)

The objective was to determine the difference of injury rates per 100 crash-involved persons, between pre- and post-standard cars, that was due to equipment installed in response to Standard 214. This difference should be measured in single vehicle crashes, in multivehicle crashes (all types), and for nearside occupants in multivehicle compartment impacts. To achieve this objective it is necessary to search for and remove biases due to vehicle age effects - i.e., differences in the occupants, vehicles and crashes of pre- and post-standard cars that are not due to Standard 214 but only to the fact that pre-standard cars are older. Part of the observed injury reduction may be due to other safety standards or side strucure modifications other than those made in response to Standard 214. Another may be due to underreporting of noninjury accidents involving older cars -- resulting in spuriously high pre-standard injury rates. It is also necessary to remove biases due to towaway criterion effects: modifications in the vehicle side structure can affect whether or not a car needs to be towed after a side impact and, thereby, affect NCSS injury rates, since NCSS is a towaway file.

Section 7.4 describes in detail the biases that may be present in side impact injury rates and Section 7.1.4 outlines the four techniques used to eliminate bias:

1. Restricting the age range of the cars under study in order to reduce the age difference between pre- and post-standard 214 cars. Unfortunately, such restrictions reduce available sample size. Thus, the approach is to perform the analysis for restricted and unrestricted samples and let the results act as a check for one another. Specifically, the analyses are performed 3 times:

(a) Comparing cars of the first two model years with beams versus cars of the last two years without them (a period during which installation of beams was the only important vehicle modification -- see Section 4.4).

(b) First five model years with beams versus last five without them.

(c) All cars with beams versus all cars without them.

Thus, analysis (a) acts to check that the results of (b) and (c) are not due to causes other than Standard 214 while (b) and (c) serve to check that the results of (a) are not a statistical fluke.

Since (a), (b) and (c) are each performed on single vehicle, multivehicle and nearside occupants in multivehicle compartment impacts, a total of 9 analyses are performed.

TABLE 2-3

SERIOUS INJURY REDUCTION ATTRIBUTED TO STANDARD
214 IN SIDE IMPACTS, NCSS

Impact type ↓ / Vehicle Age Range →	First 2 Model Years with Beams vs. Last 2 without them	First 5 Model Years with Beams vs. Last 5 without them	All Cars with Beams vs. All Cars w/o them
SINGLE VEHICLE CRASHES			
Injury reduction (%)	55	24	34
Confidence bounds	36-71	-3-40	20-44
Control variables used	Frame/unitized 2 door/4 door Nearside/farside occ.	Frame/unitized Belt usage Hardtop/pillared	Frame/unitized Hardtop/pillared Belt usage
MULTIVEHICLE CRASHES			
Injury reduction (%)	11	16	13
Confidence bounds	-3-24	7-24	2-22
Control variables used	Size of striking vehicle Rural/urban Speed limit	Rural/urban Speed limit Size of striking vehicle	Speed limit 2 door/4 door Belt Usage
NEARSIDE OCC. IN MULTIVEH. COMPARTMENT IMPACTS			
Injury reduction (%)	34	25	30
Confidence bounds	13-51	10-38	11-43
Control variables used	Size of striking vehicle Rural/urban Speed limit	Size of striking vehicle Belt usage Hardtop/pillared	Size of striking vehicle Belt usage Rural/urban

2. Using control variables correlated with Standard 214 compliance and injury risk and multivariate statistical techniques to identify the control variables causing the largest bias and then removing that bias. The procedure is essentially the same as in NHTSA's evaluation of the steering column [44]. Starting with a list of 13 potential control variables, this procedure is performed for each of the 9 analyses. Table 2-3 shows the 9 effectiveness estimates that were obtained as a result, the confidence bounds for those estimates, and the specific control variables that were selected by the procedure in preparing each of the estimates. The confidence bounds are empirically obtained by the "jackknife technique," wherein NCSS is divided into 10 systematic random subsamples of equal size and the effectiveness estimate is recalculated 10 times, each time with a different one of the subsamples removed. (See Section 7.5 for more details.)

For single-vehicle crashes, Table 2-3 shows that the procedure yielded effectiveness estimates ranging from 24 to 55 percent, with the highest effectiveness observed in the 2 year comparison. Two of the 3 estimates are statistically significant and the third comes close to it. It would appear that the 55 percent reduction, although statistically significant, may be a statistical fluke and the 24 and 34 percent estimates, over a wider range of model years, are more realistic. Nevertheless, the high effectiveness in the 2 year comparison suggests that Standard 214, not other safety standards or vehicle modifications, is primarily responsible for the injury reduction. The most important control variables tend to be vehicle structure characteristics, especially body-and-frame vs. unitized construction. These variables apparently affect whether a vehicle needs to be towed, but only in single-vehicle side impacts (see Section 7.4.6).

In multivehicle crashes, where a larger sample is available, the 3 effectiveness estimates were in close agreement, ranging from 11 to 16 percent, without any obvious trend among them. Two of the 3 estimates are statistically significant and the third comes close. The most important control variables tend to be accident descriptors, such as size of the striking vehicle or rural/urban accident location.

For nearside occupants in multivehicle impacts centered on the compartment, the 3 effectiveness estimates are all statistically significant and in close agreement, ranging from 25 to 34 percent, with the highest effectiveness observed in the 2 year comparison. The most important control variables tend to be accident descriptors. The results are strong evidence that Standard 214 is effective in this crash situation.

3. Tabulating the injury rates on NCSS by model year.

The preceding multivariate analyses successfully identified and removed many potential biases in the injury rates, but there may be some biases that cannot be removed by that procedure (e.g., underreporting of noninjury accidents of older cars -- see Section 7.1.4). As an additional check, the NCSS injury rates in single and multivehicle side impacts were tabulated by model year and examined for vehicle age trends unrelated to Standard 214. No such trend was evident in either the single or multivehicle crashes; on the other hand, when the NCSS sample is subdivided by model years, the injury rates are subject to statistical fluctuations which precluded a definitive separation of the effect of Standard 214 from possible age-related trends in the 1967-75 injury rates (see Section 7.4.5).

4. Measuring the "effectiveness" of Standard 214 in frontal impacts. Injury rates were calculated for occupants of pre- and post-Standard 214 cars that had been in single-vehicle and multivehicle frontal impacts. If Standard 214 is found to be "effective" in frontal crashes, it could indicate a bias in the frontal injury rates, which might also be present in the side impact injury rates. The analyses of frontal injury rates, which are presented in Section 7.6, did indeed indicate such a bias, especially in single-vehicle crashes, especially in the comparison of cars of the first 2 model years with beams versus the last 2 without them. The analyses suggested that the Standard 214 effectiveness estimates shown in Table 2-3 might be exaggerated by 10-20 percent in single vehicle crashes and by about 5 percent in multivehicle crashes, including nearside occupants in compartment impacts.

Finally, "best" estimates of Standard 214 effectiveness are made on the basis of the multivariate analysis results in Table 2-3, the other analyses of possible biases, and other findings of this evaluation.

The "best" estimate for single vehicle crashes is that Standard 214 reduced serious injuries by 25 percent. The effectiveness estimates in Table 2-3 ranged from 24 to 55 percent, with the highest figure based on the first 2 model years with beams versus the last 2 without them -- i.e., minimal bias due to other safety devices or age effects. The analysis of frontal crashes suggested that these estimates may be exaggerated by about 10-20 percent; this puts a "ceiling" of about 35 percent on the "best" estimate. On the other hand, the FARS analyses indicated a 23 percent fatality reduction in fixed object collisions (see Section 2.3.1). This is a "floor" on the effectiveness, since Standard 214 would be more effective against nonfatal injuries (which include many pelvic and leg injuries) than fatalities (which are to a large extent head injuries). The "best" estimate of 25 percent is a round number between the ceiling and the floor. A heuristic confidence interval for this estimate, 11 to 35 percent, is established as follows: the statistical estimate in Table 2-3 that was based on the full NCSS file was 34 percent, with confidence bounds 20-44. Since the "best" estimate is 9 percent less than that one, the confidence bounds are similarly decreased.

The 3 statistical estimates of effectiveness for nearside occupants in multivehicle compartment impacts in Table 2-3 ranged from 25 to 34 percent (average: 30 percent) and the analysis of frontal injury rates suggests the estimates are exaggerated by about 5 percent. This makes 25 percent a sensible choice for the "best" estimate. The confidence bounds, 6 to 38 percent, are again derived from the full NCSS statistical estimate in Table 2-3.

The 3 statistical estimates for all multivehicle crashes in Table 2-3 ranged from 11 to 16 percent (average: 13 percent) and the analysis of frontal crashes suggests that 5 percent be deducted, yielding a "best" estimate of 8 percent (confidence bounds: -3 to +17).

Thus, the "best" estimate for all multivehicle crashes is 1/3 as large as the estimate for nearside occupants in multivehicle compartment impacts. This is an intuitively reasonable result, since Standard 214 appears to be effective only for the latter group of persons involved in multivehicle crashes (see below) and they constitute 1/3 of the multi-vehicle side impact casualties (see Table 2-1). (See Section 7.8 for additional discussion of the "best" estimates.)

2.3.3 Nonserious injury reduction

From Texas accident files of 1972, 1974 and 1977, it was possible to select drivers of passenger cars of the last model year before beam installation, which had been involved in side impacts. Likewise, for comparable makes and models of the first model year with beams (see Sections 8.1 and 8.2). The K, A or B injury rate (where K = fatal, A = "serious" and B = "visible minor injury") decreased significantly, by 13 percent, in the Standard 214 cars in multivehicle crashes (confidence bounds: 8 to 18 percent). The rate decreased by 9 percent in single vehicle crashes; due to the relatively small sample of these crashes, the reduction was not quite statistically significant (confidence bounds: -1 to +19). (See Sections 8.3 and 8.4 for additional results and discussion.)

2.4 Why is Standard 214 effective?

2.4.1 Five hypotheses on effectiveness

The following hypotheses on why Standard 214 may be effective are stated not as facts but as conjectures. They are tested by examining the effect of Standard 214 on vehicle damage patterns and on specific types of injuries in NCSS.

Hypothesis 1: Crush Resistance In Section 2.2, it was explained that nearside occupants are vulnerable to injuries involving contact with a car's rapidly intruding door structure when the car is struck in the door area by another motor vehicle. It is hypothesized that Standard 214 slows down the rate of door intrusion, at least to some extent, because it increases the door's crush resistance. The post-Standard 214 door dissipates more energy in a shorter distance, causes the frontal structure of the striking vehicle to absorb a larger portion of the energy, allows a more rapid transfer of momentum from the striking to the struck vehicle and more effectively transmits loads to the vehicle's pillars.

This hypothesis was initially stated by Hedeen and Campbell at General Motors and is at least partially supported by results of staged crashes at GM and Chrysler (see Section 4.3).

Hypothesis 1 would appear to be relatively unimportant in collisions with fixed objects, since momentum transfer is not involved and since the sill and roof rails are immediately engaged and absorb most of the energy. It is also relatively unimportant for protecting farside occupants.

Hypothesis 2: Deflection of striking objects/vehicles In an oblique side impact, the beam acts somewhat like a highway guard rail to help partially deflect the striking vehicle or object. It helps the struck car "scrape by" -- i.e., it continues to move in a forward direction, relative to the striking vehicle or object. The potential benefits, which are not necessarily limited to nearside occupants, include

o a reduction of the velocity and depth of intrusion and of vehicle deceleration, as a result of damage being shallower and spread over a wider area.

o damage may spread from the vulnerable compartment area to the less vulnerable outer parts of the side structure.

o a reduction in Delta V, if the struck car more readily disengages itself from the striking object/vehicle.

o the integrity of door latches and hinges is more easily maintained as a result of the change in damage patterns.

This hypothesis was formulated by Hedeen and Campbell at General Motors and is supported by results of staged crashes at GM and Renault.

Hypothesis 3: Sill Override Prevention The beam holds the striking vehicle down, forcing it to engage with the struck car's sill, rather than override it. Sill engagement significantly reduces the depth and velocity of intrusion into the side structure.

This hypothesis was formulated by Hedeen and Campbell on the basis of GM crash test results.

Hypothesis 4: Greenhouse Protection The beam provides a strong horizontal component in the side structure parallel to and above the sill. It prevents the car from partially "tipping over" into a fixed object and keeps the object away from the extremely vulnerable greenhouse area of the car (the part of the passenger compartment above the beltline).

This hypothetical effect does not appear to have been mentioned elsewhere in the literature.

Hypothesis 5: Door Integrity Protection The beam helps the door maintain its basic shape during a crash, preventing it from being deformed to the point where it separates from hinges, latches or from the vehicle. As a result, there are fewer occupant ejections through the door.

Hypothesis 5 may, in part, be a beneficial side effect of hypotheses 2 or 1. It does not appear to have been mentioned elsewhere in the literature.

2.4.2 Effect of Standard 214 on vehicle damage patterns

The NCSS file contains measurements of the depth and width of vehicle crush. The measurements were taken for the purpose of operating a computer program to estimate Delta V, but they are useful for the purposes of this evaluation as well. The "depth of crush," as used in this discussion, is the maximum of the 4-6 depth measurements on NCSS. Table 2-4 compares the mean values of crush depth and width in pre- and post-Standard 214 cars. As in the preceding analysis of injury reduction, values are obtained 3 times:

(a) For cars of the first two model years with beams versus the last two years without them

(b) First 5 years with beams vs. last 5 years without them

(c) All cars with beams vs. all cars without them

Moreover, the values in Table 2-4 have been adjusted by a multiple regression procedure that controls for the effects of side structure modifications other than Standard 214 (e.g., hardtops vs. pillared cars -- see Section 9.3.1 for details).

Table 2-4 shows that Standard 214 made damage patterns about 20 percent shallower and wider in single vehicle side impacts. The deepest penetration decreased from an average of 10-11 inches in pre-standard cars to 7-9 inches in post-standard cars while the width of the damaged area increased from 40-45 inches to 50-53 inches. The results were nearly identical for the restricted sample (2 years before vs. 2 years after) and the wider age ranges, indicating that Standard 214 caused this change, not vehicle age-related trends (such as a change in crash configurations or Principal Direction of Force). This is strong evidence in favor of Hypothesis 2 for single vehicle crashes: Standard 214 has helped a car "scrape by" a fixed object. Moreover, detailed analyses in Section 9.3.2 indicate that this benefit is not limited to impacts centered on the compartment but, to a lesser extent, is also present in impacts that peripherally involve the compartment.

Table 2-4 shows that Standard 214 reduced the depth of crush by 20 percent in multivehicle impacts centered on the compartment but had no effect on the width of the damaged area. The deepest penetration decreased from an average of 10-11 inches in pre-standard cars to 8-9 inches in post-standard cars, but the width of the damaged area was unchanged. The results were nearly identical for the restricted and unrestricted samples, indicating that Standard 214 caused this reduction of crush depth, not vehicle age-related trends. The significant reduction of crush depth could be evidence in favor of either Hypothesis 1 (direct crush resistance) or 3 (sill override prevention) in multivehicle crashes. Hypothesis 2 (deflection) would not appear to be valid because the reduction in depth is not accompanied by an increase in width. Moreover, additional

TABLE 2-4

EFFECT OF STANDARD 214 ON DEPTH AND WIDTH OF VEHICLE DAMAGE

Impact Type ↓ / Vehicle Age Range →	First 2 Model Years with Beams vs. Last 2 w/o them	First 5 Model Years with Beams vs. Last 5 w/o them	All Cars with Beams vs. All Cars w/o them
SINGLE VEHICLE CRASHES			
Depth of crush (inches)			
pre	11	10	10
post	9	7*	8*
Width of damaged area (inches)			
pre	40	44	45
post	50*	53*	50
MULTIVEHICLE CRASHES, CENTERED ON COMPARTMENT			
Depth of crush (inches)			
pre	11	10	10
post	9*	8*	8*
Width of damaged area (inches)			
pre	75	54	53
post	73	54	53

*Statistically significant change

data presented in Section 9.3.3 suggests that depth reduction is limited to crashes _centered_ on the compartment. No reduction was found for impacts that peripherally damage the compartment but whose damage center is outside a zone extending from 45 inches in front of the car's midpoint to 15 inches behind it. This is a major reason why impacts that only peripherally damage the compartment have, throughout this evaluation, been excluded from the definition of "compartment impacts."

A second major benefit in _single_ vehicle crashes -- and another piece of evidence in favor of Hypothesis 2 (deflection) -- is that Standard 214 has _reduced_ the incidence of crashes with damage centered on the compartment while increasing the likelihood that the compartment is damaged peripherally or not at all. The percentage of single-vehicle crash involved cars whose damage was centered on the compartment decreased from 63 percent of cars of the last 2 model years without beams to 40 percent of cars of the first 2 years with beams; from 50 percent of cars of the last 5 years without beams to 38 percent of the first 5 with beams; from 48 percent of all pre-standard cars to 39 percent of all post-standard cars. These decreases were generally accompanied by increases in _both_ the percentage of cars with peripheral compartment damage and those with damage restricted to areas away from the compartment. It seems that when a fixed object strikes the door, Standard 214 helps deflect the object and _spread_ the damage out to the fenders -- Hypothesis 2. But when the object initially contacts the fenders, Standard 214 may help _prevent_ the damage from spreading to the door -- possibly by increasing the longitudinal strength of the vehicle.

None of these effects on damage location is present in multivehicle crashes: 31 percent of pre-standard cars had damage centered on the compartment, as did 31 percent of cars of the first 2 years with beams, 32 percent of the first 5 years with beams and 34 percent of all post-standard cars. This is further evidence that Standard 214 has not been effective in deflecting a striking vehicle, but only a fixed object. (See Section 9.4 for details on the analyses of damage location.)

Table 2-5 shows that the incidence of sill override in multi-vehicle crashes was 41 percent lower in cars of the first 2 model years with beams than in cars of the last 2 years without them; this is a statistically significant reduction. The incidence of sill override decreased by a significant 25 percent when cars of the first 5 years with beams were compared to cars of the last 5 years without them; for the unrestricted sample the reduction in sill override was a nonsignificant 18 percent. From these results, it seems likely, although not certain, that Standard 214 reduced the incidence of sill override by about 20 percent. Thus, Hypothesis 3 (sill override prevention) seems to be at least partially valid in highway accidents.

What proportion of the overall crush reduction in multivehicle crashes can be attributed to Hypothesis 3? Based on the effect of sill override on crush in staged crashes, the incidence of sill override in pre-Standard 214 cars and the reduction observed for Standard 214, it is estimated in Section 9.6 that 13 percent of the overall crush reduction in multivehicle crashes is attributable to sill override prevention.

TABLE 2-5

REDUCTION, FOR STANDARD 214, IN SILL OVERRIDE, GREENHOUSE DAMAGE AND EJECTION

Vehicle Age Range / Reduction (%) of	First 2 Model Years with Beams vs. Last 2 w/o them	First 5 Model Years with Beams vs. Last 5 w/o them	All Cars with Beams vs. All Cars w/o them
Sill override in multivehicle Crashes	41*	25*	18
Greenhouse damage in single veh. crashes	0	13	14
Occupant ejection through doors			
In single-veh. crashes	68*	75*	56*
In multiveh. crashes	12	56*	72*
Door opening during impact			
In single-veh. crashes	20	38	40
In multiveh. crashes	21	36*	41*
Latch or hinge damage			
In single-veh. crashes	19*	8	11
In multiveh. crashes	1	5	2

*Statistically significant reduction

The remainder (87 percent) of the crush reduction, then, must be attributed primarily to Hypothesis 1 (crush resistance), since as noted before, Standard 214 did not appear to be effective in deflecting a striking vehicle.

Table 2-5 indicates that cars of the first 2 model years with beams had the same incidence of greenhouse damage in single vehicle crashes as cars of the last 2 years with beams. In the 5-year and full-NCSS comparisons, however, greenhouse damage was 13-14 percent less common in the post-standard cars. The reductions are not significant; moreover, they may be a consequence of Standard 214's tendency to reduce compartment damage generally, rather than evidence of a specific greenhouse protection capability. Thus, the NCSS data do not strongly support Hypothesis 4 (greenhouse protection), although they do not rule it out. (See Section 9.7 for additional discussion.)

Finally, both FARS and NCSS show such a strong reduction of occupant ejection for Standard 214, especially in fixed object collisions, that Hypothesis 5 (door integrity protection) simply cannot be denied.

In FARS, there were 24 percent fewer fatal ejections in cars of the first 2 model years with beams in nonrollover side impacts with fixed objects than in cars of the last 2 years without them (reduction is measured relative to frontal fatalities - see Section 10.3). The reduction is even higher than the corresponding reduction of nonejection fatalities (22 percent). Since no major vehicle modification occurred during those model years other than the installation of beams, this significant reduction of ejection must have been a result of Standard 214. (Specifically, the installation of door latches and hinges meeting Standard 206 took place 4-8 years before the implementation of Standard 214.)

Likewise, Table 2-5 shows that, on NCSS, occupants of cars of the first 2 years with beams were 68 percent less likely to be ejected through the door area in a nonrollover, single vehicle side impact than in cars of the last 2 years without beams. This significant reduction of door ejection for Standard 214 cars persisted in the 5-year comparison (75 percent) and in the analysis of the full NCSS (56 percent). Also, in single-vehicle side impacts, the likelihood of at least one door opening during the crash decreased by 20-40 percent for the post-Standard 214 cars. The likelihood of damage to at least one latch or hinge decreased by 8-19 percent.

This is strong evidence that Standard 214, in single vehicle crashes, helps preserve the integrity of the door structure and reduces the likelihood of door ejection: a major reason why Standard 214 saves lives and reduces serious injuries in single vehicle crashes.

The NCSS data on multivehicle crashes do not support equally firm conclusions about ejection -- which, in any case, is not a major injury source in multivehicle side impacts (see Table 2-2). Cars of the first 2 years with beams had a 12 percent lower frequency of occupant ejection through doors and a 21 percent reduction in the incidence of door opening; neither reduction is statistically significant. There were much larger, statistically significant reductions of ejection and door opening in the 5-year and full-NCSS comparisons, but in these cases it is not clear that the reduction is necessarily due to Standard 214. It is plausible to conclude that Standard 214 may have reduced ejection through doors by about 20 percent in multivehicle crashes (See Section 9.8 for further discussion on ejection.)

2.4.3 Effect of Standard 214 on specific types of injuries

The benefits of Standard 214 in single vehicle crashes are not limited to reducing nearside occupants' torso injuries due to contact with the side structure. The following effectiveness estimates for various types of injuries resulting in death or hospitalization are based on a comparison of all post-Standard 214 NCSS cases to all pre-standard cases (see Section 10.2). The estimates may be biased in favor of Standard 214 by about 10-20 percent, for reasons discussed in Section 2.3.2. But even if 10-20 percent is subtracted from each estimate, it is evident that Standard 214 is at least partially effective in preventing many types of injuries.

Torso, arm and leg injuries due to contact with side interior surfaces (doors, pillars, armrests, etc.) were 41 percent less frequent in post-standard than in pre-standard cars. Most of these injuries had occurred among nearside occupants; for them, the reduction for Standard 214 was 50 percent. This is strong evidence that Standard 214 has achieved, in single vehicle crashes, its stated goal of reducing the incidence of nearside occupant's torso injuries due to side surface contact. Farside occupants experienced a 23 percent reduction of these injuries, indicating that Standard 214 may also be partially effective for them.

Head injuries due to contact with side surfaces decreased by 25 percent. Again, most of the victims in pre-standard cars were nearside occupants; for them, the reduction was 29 percent. Farside occupants experienced a 16 percent reduction of side contact head injuries.

Since head injuries are a substantially larger percentage of fatalities than of nonfatal serious injuries, the apparent effectiveness of Standard 214 is reducing them may be a major factor in the standard's fatality reduction in single vehicle crashes.

Injuries due to contact with frontal components (the steering assembly, dashboard, etc.) declined by 27 percent. The observed reduction for nearside occupants was 46 percent, a definite indication that the standard is at least partially effective. The reduction for farside occupants was only 13 percent and can probably be attributed to safety standards other than 214.

These reductions in head injuries, frontal contacts, and nearside and farside occupants' torso injuries due to side contact are consistent with Hypothesis 2 -- that Standard 214 helps a vehicle scrape by or be partially deflected from a fixed object. As explained in Section 2.4.1, this effect reduces crush depth in the compartment area, protecting nearside occupants. But, more generally, it reduces the overall severity of the impact, protecting farside occupants and reducing the harshness of interior contacts. The reduction of nearside occupants' head injuries could also be evidence for Hypothesis 4 (greenhouse protection) or it could partly be due to Standard 214's property of spreading damage from the compartment to other areas. Nearside occupants' frontal contact injuries were reduced to such a large extent, perhaps, because many of them occurred after the occupant rebounded from the side structure.

Finally, injuries due to contact with exterior objects decreased by 63 percent, consistent with the large reduction of occupant ejection (see Section 2.4.2). Exterior contact reductions were nearly identical for nearside occupants (56%) and farside occupants (73%). The reduction of ejection may be the primary source of net benefits for Standard 214 for farside occupants in single vehicle crashes.

In multivehicle crashes, there was a 33 percent reduction of nearside occupants' serious torso, arm and leg injuries due to contacting the side surface in an impact centered on the compartment. Clearly, Standard 214 has eliminated a substantial proportion of the injuries it was designed to eliminate. This effect accounts for virtually all the benefits of Standard 214 in multivehicle crashes: this type of injury accounts for 24 percent of all serious multivehicle side impact injuries, according to Table 2-2. If about 30 percent of these injuries are eliminated, it amounts to eliminating 7 percent of all serious injuries (i.e., 30 percent of 24 percent) -- which is nearly the entire overall reduction (8%) attributed to Standard 214 in multivehicle crashes (see Section 2.3.2).

On the other hand, there was no reduction of torso, arm and leg injuries due to side surface contact for farside occupants or in impacts that were not centered on the compartment (observed effect: a 10% increase). There was a 1 percent reduction in head injuries due to side surface contacts and no change in the injuries due to contact with frontal components. In short, Standard 214 had no effect on any other type of injury within the vehicle.

This pattern is consistent with the analyses of damage data. The effect of Standard 214 in nonejection multivehicle crashes is limited to a reduction of intrusion in compartment impacts, primarily because of Hypothesis 1 (increased crush resistance) and partly due to Hypothesis 3 (sill override prevention). As a result, the injuries that are most likely due to contact with intruding side surfaces are significantly mitigated -- i.e., nearside occupants' torso injuries due to side surface contact in compartment impacts. But Standard 214 is apparently not effective in helping to deflect the striking vehicle (Hypothesis 2) and does not reduce the overall severity of a crash or modify the car's performance in crashes, other than reducing intrusion. As a result, there is no significant reduction of any other type of nonejection injury.

There was a 57 percent reduction of injuries due to exterior contacts, consistent with the 72 percent reduction of occupant ejection in the analysis of the full NCSS file (see Table 2-5). Since the reduction of ejection in the 2 year comparison was only 12 percent, it is suspected that the large reduction of exterior contact injuries may be partly due to factors other than Standard 214. Since exterior contacts accounted for only 5 percent of the serious injuries in multivehicle crashes (see Table 2-2), the net benefits of their reduction are relatively small.

The preceding analyses supply 2 reasons why Standard 214 may not be effective in preventing fatalities in multivehicle crashes, even though it reduces serious injuries:

o Head injuries are very fequently a cause of deaths (much more so than serious injuries) and they are not significantly mitigated by Standard 214 in multivehicle crashes.

o In multivehicle crashes, Standard 214 relies on a reduction of crush depth, mainly due to the door's increased crush resistance. In an extremely severe impact, the percentage of energy absorbed or momentum transferred through the door structure (as opposed to pillars and other strong components) is small and the increase in this percentage due to Standard 214 is too small to appreciably reduce intrusion velocity.

2.4.4 Summary

Based on the preceding analyses of damage patterns and specific injury types, the primary explanation for the effectiveness of Standard 214 in single vehicle crashes is Hypothesis 2 -- deflection of striking objects. Hypothesis 5 -- reduction of ejection through doors -- is also a major source of benefits. The effectiveness is not limited to nearside occupants in compartment impacts and includes fatality as well as serious injury reduction.

In multivehicle crashes, the benefits are mainly limited to a reduction of nearside occupants' nonfatal torso injuries due to contact with intruding side surfaces and are primarily explained by Hypothesis 1 -- increased crush resistance. Sill override prevention (Hypothesis 3) made a much smaller contribution to benefits. There may also have been a reduction of ejections (Hypothesis 5).

The overall effectiveness of Standard 214 may be allocated among the hypotheses as follows (see Section 9.9 for more details):

	Casualty Reduction for Standard 214 (%)			
	In Fixed Object Crashes		In Multivehicle Crashes	
	Nonfatal Hospitalizations	Fatalities	Nonfatal Hospitalizations	Fatalities
1. Crush resistance	Negl.	Negl.	6	Negl.
2. Deflect objects or vehicles	19	17	Negl.	Negl.
3. Prevent sill override	—	--	1	Negl.
4. Protect greenhouse	Possible	Possible	--	--
5. Protect door integrity (prevent ejection)	6	6	1	Negl.
TOTAL	25	23	8	Negl.

2.5 Costs, benefits and cost-effectiveness

The cost of Standard 214 is the average annual fleetwide cost of safety equipment which was actually installed in response to the standard in cars of the type that were sold during 1979-82. The costs are expressed in 1982 dollars.

The cost includes the net increase in the lifetime cost of owning and operating an automobile. There are 2 principal sources of increased cost:

(1) The initial price increase due to the added safety equipment

(2) The lifetime increase in fuel consumption due to the incremental weight of the equipment.

The side door beam assemblies of 15 late model cars were torn down and examined in detail (see Section 11.1). The price and weight increases were estimated for each of them. The price increase includes materials, labor, tooling, assembly, overhead, manufacturer's and dealer's markups and taxes. A sales weighted average was used to determine the overall cost and weight, per car, for side door beam assemblies: $28 and 26 pounds.

The preceding analysis was limited to the side door beam itself and its associated parts. The only other vehicle modification in response to Standard 214 appears to have been a local reinforcement of the B pillar at the floor level, or an equivalent supporting device. This was estimated to cost at most $2 and weigh about 2 pounds per car. Thus, the total cost and weight per car for Standard 214 is estimated to be

- $30 (in 1982 dollars)
- 28 pounds

Each pound of weight added to a car results in an extra gallon of fuel consumption over the lifetime of the average car [29]. At 1982 fuel prices, this results in a penalty whose present value is $1.093 per added pound. In other words, the average lifetime cost of Standard 214, including fuel, is $61 per car. Since 10 million cars were sold annually during 1971-81, the average annual cost of Standard 214 is $610 million. (See Section 11.1 for more details.)

The benefits of Standard 214 are the fatalities and injuries that will be prevented annually in highway accidents, as a consequence of the safety modifications described above, when all cars meet the standard. The benefits are estimated in Section 11.2 to be the following:

	Best Estimate	Confidence Bounds
LIVES SAVED in single vehicle crashes	480	300 to 660
NONFATAL HOSPITALIZATIONS ELIMINATED		
In single-vehicle crashes	4550	900 to 8200
In multivehicle crashes	4920	800 to 9000
TOTAL	9470	4,300 to 14,700
"VISIBLE MINOR" (LEVEL B) INJURIES ELIMINATED (In multivehicle crashes)	15,000	

The cost-effectiveness of Standard 214 is the number of Equivalent Fatality Units (EFU) eliminated per million dollars of cost. The EFU is a single quantity that measures the number of lives saved and hospitalizations prevented by a standard. Each life saved is a benefit of 1 EFU; each nonfatal hospitalization prevented is a benefit of 0.0592 EFU (see Section 11.3). The reduction of "visible minor" (level B) injuries was not included in the calculation of EFU, due to the low severity of the injuries.

Standard 214 was estimated to save 480 lives; that is a contribution of 480 EFU. It will eliminate 9470 nonfatal hospitalizations; that is a contribution of 560 EFU. Thus, a total of 1040 EFU will be eliminated annually when all cars meet Standard 214 (confidence bounds: 700 to 1380).

Since Standard 214 eliminates 1040 EFU and costs $610 million per year, it eliminates 1.7 Equivalent Fatality Units per million dollars of cost (confidence bounds: 1.1 to 2.3).

2.6 Comparison with NHTSA's 1979 preliminary evaluation

A preliminary evaluation of Standard 214 was published by NHTSA in 1979, based on a NCSS file that was less than half complete at that time [46]. It was published with a promise that a followup would be performed. The results and conclusions of this report supersede the preliminary evaluation. Sections 1.3 and 5.5 describe the additional data sources and analysis techniques that were available for this follow-up evaluation. Here, however, is a summary of the principal findings and conclusions of the 1979 report, with comments as to which ones are still supported by the current results.

Principal Findings - 1979 report:

o The 1979 report estimated that, in the absence of Standard 214, single vehicle side impact fatalities outnumbered multivehicle by 4 to 3. That was based on a NCSS sample of 67 fatalities. The current report, based on FARS, suggests the ratio is the other way.

o The preliminary estimate of serious injury reduction in single vehicle crashes was 66 percent, published with a warning that it was likely to change. The current estimate, based on a much larger sample and new techniques for removing biases, is 25 percent.

o The preliminary report observed a nonsignificant increase in multivehicle crash injury rates. With the full NCSS, the current report finds a significant injury reduction.

o The earlier report contained two estimates of lives saved: 2800 (based on single vehicle crashes) and 2350 (based on all types of side impacts). These NCSS estimates were subject to large sampling errors and biases. It is doubtful that the reductions were really due to Standard 214. The current estimate of 480 is based on FARS and can be reliably attributed to Standard 214.

o The 1979 report estimated that serious injuries, in single and multivehicle crashes combined, were reduced by a nonsignificant 17 percent. This report contains a virtually identical, but now statistically significant, estimate of 14 percent (i.e., 9950 out of 73,600 fatalities and hospitalizations were eliminated).

o The preliminary evaluation analyzed intrusion and injury reduction as a function of the Principal Direction of Force on the vehicle. Since the current report finds that Standard 214 itself significantly changed the PDOF's recorded by NCSS investigators (see Section 9.5), those analyses present a conceptual difficulty.

o The preliminary cost estimate was $56 per car (in 1977 dollars), which is equivalent to $79 in 1982 dollars and fuel prices (see Section 11.1). The estimate was published with a note that costs were probably decreasing as a result of downsizing. Indeed, the current report is based on more recent cars and contains an estimate of $61 in 1982 dollars.

o The 1979 report, after costs are expressed in 1982 dollars, gave 2 estimates of cost-effectiveness: 2.0 EFU per million dollars (based on the overall AIS $\geqslant$ 3 reduction) and 3.6 (based on the AIS $\geqslant$ 3 reduction in single vehicle crashes and setting the benefits in multivehicle crashes to zero -- see [46], pp. 20-21). The current estimate is 1.7 EFU per million dollars (confidence bounds: 1.1 to 2.3).

Conclusions - 1979 report:

o The 1979 report concluded that Standard 214 is effective in <u>single</u> vehicle side impacts. The current report strongly supports that conclusion.

o The earlier report concluded that Standard 214 "accomplished its purpose" of reducing intrusion in oblique crashes. As noted above, the current report finds conceptual difficulties with such a conclusion. On the other hand, the current report concludes that Standard 214 "accomplished its goal" of reducing depth of intrusion <u>and</u> nearside occupants torso injuries due to contact with intruding side structures in both single <u>and</u> multivehicle crashes.

o The preliminary report concluded that a large percentage of serious casualties involved collisions with fixed objects and/or oblique forces. Somewhat analogous are the findings of this report that nearside occupants' torso injuries due to contact with intruding side structures in multivehicle crashes account for fewer than 25 percent of fatalities and serious injuries.

o The earlier report concluded that Standard 214 is effective in single vehicle crashes because it enables a car to "slide by" a fixed object. The current report strongly supports this conclusion, presenting evidence of this effect in NCSS damage data and staged crashes.

o The 1979 report concluded that Standard 214 is significantly less effective in multivehicle than in single vehicle crashes. Although the current report finds a significant benefit for Standard 214 in nonfatal multivehicle crashes and the effectiveness estimate in single vehicle crashes is lower than before, it still supports the earlier conclusion strongly, especially in fatal accidents.

2.7 Strengths and weaknesses of the evaluation

The principal strength of the evaluation was the high degree of consistency between the statistical results on fatality and injury reduction, the detailed analyses of side structure performance in crashes and specific types of injuries, and the explanations of Standard 214 effectiveness based on engineering analyses and staged crashes.

Seven years of FARS data contained so many fatalities that it was possible to restrict the analysis to the year (or 2 years) before and after Standard 214 implementation and to obtain estimates of fatality reduction that could reliably be attributed to Standard 214.

The complete NCSS file, in combination with the analysis techniques developed for this evaluation, made it possible to obtain statistically reliable results on serious injury reduction and conduct a detailed search for and removal of potential biases in the estimates. The NCSS file was of ample size for the analyses of damage patterns. On the other hand, a larger file would have improved the analyses of overall and specific injury reduction: it would have made it possible to rely entirely on cars built just before or after beam implementation, as with

FARS. Instead, it was necessary to analyze injury reduction for restricted <u>and</u> unrestricted age ranges. The analyses acted as useful checks on each other, but they made the work more complicated.

Detailed cost analyses were limited to the side door beam assembly. An approximate cost and weight estimate was added for local reinforcements at the floor of the B pillar, or equivalent supporting structures. It appears from the literature that these were the only major side structure modifications made in response to Standard 214 in cars during 1969-82, but cost estimates might have to be revised if there is evidence that other changes were made <u>because of</u> Standard 214.

Finally, the approach of performing separate effectiveness analyses for 3 major classes of side impacts -- all nonrollover single vehicle crashes (including farside occupant and noncompartment impacts); all multivehicle crashes; nearside occupants in multivehicle compartment impacts (with a narrow definition of "compartment impact") -- proved to be suitable in view of the quite different injury mechanisms and hypothetical actions of Standard 214 in the 3 crash types.

2.8 Conclusions

The analyses of this evaluation, which have isolated the effects of Standard 214 from other safety standards (201, 203, 204, 205, 206, 208-210, 216) and vehicle modifications (pillared hardtops, type of body structure, number of doors), support the following conclusions on the effect of Standard 214:

<u>Single-vehicle side impacts</u>

o Standard 214 has significantly reduced fatalities <u>and</u> serious injuries in single vehicle crashes.

o The standard has helped cars "glance by" fixed objects, limiting the damage in the compartment area and spreading it to less vulnerable regions of the car. It has reduced the overall severity of the collision, not only for persons sitting next to the damaged area but also, to a lesser extent, for the other occupants.

o It has thereby also helped protect the integrity of the door structure, significantly reducing the risk of occupant ejection, even in potentially fatal crashes.

o The standard has accomplished the goal of reducing nearside occupants' torso, arm and leg injuries due to contact with the car's side structure.

o But the standard's benefits also extend to head injuries, contacts other than the side structure, and farside occupants, because it has made crashes generally less severe and it has reduced ejection. For these reasons, it has significantly reduced fatalities as well as nonfatal serious injuries.

Multivehicle side impacts

o Standard 214 has significantly reduced nonfatal serious injuries and nonserious injuries in multivehicle crashes.

o It has had little or no effect on fatalities.

o The standard has reduced side structure intrusion when the car is directly impacted in the compartment by another vehicle. The reduction is primarily a consequence of increased crush resistance.

o It does not appear to significantly promote deflection of the striking vehicle -- the effect that was prominently displayed in fixed object collisions.

o The standard may have been partially effective in preventing the striking vehicle from overriding the sill. This effect, at best, accounts for only a small portion of the standard's benefit in multi-vehicle crashes.

o The standard may have reduced occupant ejection -- a mechanism that accounts for a much smaller percentage of the injuries in multi-vehicle than in single vehicle crashes.

o The standard has accomplished its goal of significantly reducing nearside occupants' torso, arm and leg injuries due to contact with side structures in compartment impacts. These lesions constitute a large portion of the serious nonfatal injuries but a much smaller portion of the fatalities.

o But the standard appears to have had negligible effect on all other types of injuries (except, possibly, ejections).

o The standard has had negligible effect on fatalities, primarily, because it has not significantly reduced head injuries and also, perhaps, because the added crush resistance in the doors, without other major modifications, is of little use in extremely severe crashes.

o Although Standard 214 has had significant benefits in multi-vehicle crashes, they are exceeded by the benefits in single vehicle crashes.

CHAPTER 3

THE SIDE IMPACT SAFETY PROBLEM

Impacts to the side of a passenger car rank second only to frontal crashes as a source of occupant fatalities and serious injuries. This crash mode is especially dangerous when the impact is on the passenger compartment because there is relatively little energy-absorbing "metal" between the occupants and the point of contact.

The first part of this chapter establishes the magnitude of the safety problem: the number of fatalities and serious injuries per year that would be occurring if Standard 214 had not been promulgated, as estimated from Fatal Accident Reporting System (FARS) and National Crash Severity Study (NCSS) data, respectively. The second part is a review of the engineering literature and staged test experience. It describes the injury mechanisms in side impacts and the vehicle factors which aggravate injury risk. In the last part, the relative importance of the various injury mechanisms and contributing factors is statistically assessed, based on NCSS, FARS and General Motors accident data.

3.1 The number and severity of casualties in side impacts

3.1.1 Fatalities

The 1980 FARS file, the last year for which complete records were available (as of July 1982) is chosen as the "base" for the fatality estimate. It contains records of 7668 passenger car occupant fatalities whose cars were explicitly stated to have had primary damage in the side. (In other words, the primary impact point was coded 2-4 or 8-10.) An estimate of the number of fatalities that would have occurred in 1980 if Standard 214 had not been promulgated is obtained by adding the number of lives that the standard is currently saving (if any) plus a prorating of the fatalities with unknown damage location. The estimation is performed separately for single-vehicle and multivehicle crashes.

There were 2910 passenger car fatalities on the 1980 FARS explicitly stated to have occurred in a single-vehicle crash involving a car that was damaged in the side. Based on formulas and procedures documented in Section 11.2.1, that actual count should be augmented by approximately 100 single-vehicle crash fatalities of unstated crash modes (prorated according to the distribution of known crash modes) and 350 lives that were saved by Standard 214. This gives an estimate of 3360 fatalities that would have occurred in single-vehicle side impacts in 1980, in the absence of Standard 214. There is very little statistical uncertainty about this estimate because the vast majority of the fatalities (2910) actually happened and were reported on FARS: the confidence bounds for the estimate are 3210-3510 (one-sided α = .05; see Section 11.2.1).

There were 4758 actual fatalities on FARS that were stated to have occurred in cars damaged in the side in a multivehicle accident. That count should be augmented by 50 of the multivehicle crash fatalities with unknown impact site, yielding a total of 4808 deaths that actually occurred in 1980. Since this evaluation makes no claim that Standard 214 saves lives in multivehicle crashes, it is concluded that essentially 4808 deaths would also have occurred in 1980 even if Standard 214 had not been promulgated.

The total number of side impact fatalities that would have occurred in 1980 is 8168, the sum of the deaths in single-vehicle (3360)

TABLE 3-1

NUMBER OF SIDE IMPACT FATALITIES THAT WOULD HAVE OCCURRED IN 1980, IF STANDARD 214 HAD NOT BEEN PROMULGATED, BY NUMBER OF VEHICLES AND OCCUPANT LOCATION

	N of Deaths	Percent of Subtotal
In single-vehicle crashes	3360*	
Nearside occupants		58
Farside occupants		42
In multivehicle crashes	4808	
Nearside occupants		69
Farside occupants		31
TOTAL	8168	

*Confidence bounds: 3210 - 3510 (one-sided α=.05) and multivehicle (4808) crashes. That is about 30 percent of all passenger car occupant fatalities.

Table 3-1 shows that 58 percent of the fatalities in single-vehicle crashes were nearside occupants. A "nearside" occupant is one who sat adjacent to the side of the car that was struck - i.e., a driver or left-rear passenger in a left-side impact; a right-front or right-rear passenger in a right-side impact. Nearside occupants are especially vulnerable because they are likely to make immediate contact with a damaged and possibly intruding side structure. All other occupants, including those in center-seat positions are "farside" occupants; they accounted for 42 percent of the single-vehicle crash fatalities. In multivehicle crashes, the predominance of nearside fatalities was even greater: 69 percent. (The distribution of fatalities by seat position is based on the column totals in Tables 6-3 and 6-4).

3.1.2 Hospitalizations

The National Crash Severity Study (NCSS), a large sample of towaway crashes investigated in 1977-78, is used to obtain estimates of the number of serious injuries - fatalities and (at least) overnight hospitalizations - that would have happened in 1980 if Standard 214 had not been promulgated. The file is described in more detail in Section 7.1 and in [44], pp. 138-148. The estimation formulas, which are similar to those used in the steering column evaluation ([44], pp. 68-73, 185-186 and 203-204) are documented in Section 11.2.2. Essentially, the number of casualties in NCSS predicted by the models of Section 7.5 if no cars meet Standard 214 are multiplied by the ratio of actual 1980 passenger car fatalities (from FARS) to the fatalities on NCSS (with appropriate correction factors).

Note that the estimates in this section include hospitalizations <u>and</u> fatalities. For estimates of nonfatal hospitalizations, the fatality estimates from Section 3.1.1 should be subtracted from the estimates in this section.

All crashes that are primarily <u>rollovers</u> are <u>excluded</u> throughout the NCSS analyses.

It is estimated that a total of 73,600 side impact fatalities and hospitalizations would have occurred in 1980 if Standard 214 had not been promulgated (confidence bounds: 67,300-80,000). Just over 8000 of these casualties would have been fatalities (see Table 3-1); the remainder, hospitalizations.

An estimated 20,100 of the side impact casualties occurred in <u>single-vehicle</u> crashes (confidence bounds: 16,400 - 23,800). Thus, single-vehicle crashes account for a smaller proportion of the fatalities and hospitalizations (20,100 out of 73,600, or 27%) than of the fatalities alone (3360 out of 8168, or 41% - see Table 3-1). The remaining 53,500 casualties occurred in cars that were struck in the side by another motor vehicle (confidence bounds: 48,100 - 59,000).

The NCSS data make it possible to distinguish nearside and farside occupants and, moreover, whether or not the impact was centered on the passenger <u>compartment</u>. Compartment-centered crashes pose an exceptional hazard to nearside occupants, who are likely to come into immediate contact with the intruding side structure of the compartment (see Section 3.2). Throughout this evaluation, a more restrictive definition of "compartment-centered crash" is used than in earlier reports. Here, it is those crashes in which the midpoint of the damage is within a zone extending from 45 inches in front of the midpoint of the car to 15 inches behind the midpoint. In earlier studies [11], [40], [43], [46], "compartment crashes" included any car whose damage at least partially overlapped the compartment. The earlier definition resulted in the inclusion of many crashes in which compartment damage is so peripheral as to be irrelevant to vehicle structure performance and injury causation. The appropriateness of the more restrictive definition for the evaluation of Standard 214 is born out in Sections 9.3.3 and 10.1, where it is shown that the standard has essentially no effect in multivehicle crashes when damage is not centered on the compartment.

The net effect of the new definition, however, is that a smaller percentage of side impact casualties are "nearside occupants in compartment crashes" than was indicated by previous reports. The implication, as will be discussed further in Sections 3.2 and 3.3, is that the safety problem associated with intruding side structures may be somewhat smaller than was indicated in earlier reports.

Table 3-2 shows that 36 percent of the fatalities and hospitalizations in single-vehicle crashes are nearside occupants of cars with damage centered on the passenger compartment. Another 17 percent are nearside occupants of cars where the midpoint of the damage was outside the door zone and 47 percent are farside occupants.

The distribution of casualties in multivehicle crashes is nearly identical: 37 percent are nearside occupants in compartment impacts. Since

TABLE 3-2

NUMBER OF SIDE IMPACT FATALITIES AND HOSPITALIZATIONS THAT WOULD HAVE OCCURRED IN 1980, IF STANDARD 214 HAD NOT BEEN PROMULGATED, BY NUMBER OF VEHICLES, OCCUPANT LOCATION AND IMPACT SITE

	N of Deaths and Hospitalizations	Confidence Bounds*	Percent of Subtotal
In single-vehicle crashes	20,100	16,400 - 23,800	
Nearside occupants - damage centered on compartment			36
Nearside occupants - damage not centered on compartment			17
Farside occupants			47
In multivehicle crashes	53,500	48,100 - 59,000	
Nearside occupants - damage centered on compartment	(19,700)	15,800 - 23,600	37
Nearside occupants - damage not centered on compartment			20
Farside occupants			43
TOTAL	73,600	67,300 - 80,000	

*One-sided $\alpha = .05$

this category is shown to be especially relevant to the evaluation of Standard 214 (see Chapters 7, 9 and 10), its magnitude is separately estimated in Section 11.2.2. That estimate is 19,700 nearside casualties in multivehicle compartment crashes (confidence bounds: 15,800 - 23,600). Another 20 percent of the multivehicle crash casualties are nearside occupants in cars with damage not centered on the compartment and 43 percent are farside occupants.

(The percentages in Table 3-2 are derived as follows: for single -vehicle crashes, they are the actual percentage distributions of the 178 pre-Standard 214 casualties on NCSS. For multivehicle crashes, separate estimates are obtained in Section 11.2.2 for all crashes and for nearside occupants in compartment crashes. The latter estimate is 37 percent of the former. The remaining 63 percent is apportioned among nearside-noncompartment and farside according to the actual distributions of the 302 pre-Standard 214 casualties in these two categories on NCSS.)

3.1.3 AIS distribution

Table 3-3 shows the distribution of Abbreviated Injury Scale [1] ratings for occupants of pre-Standard 214 cars who were hospitalized but survived a side impact (single vehicle, multivehicle and nearside occupants in multivehicle compartment impacts). In this table, the occupant's AIS rating is the rating given to his most severe injury (i.e., not the "Overall AIS" which has been used in other studies). Table 3-3 is based on actual counts in pre-standard cars on NCSS.

In single-vehicle crashes and for nearside occupants in multivehicle compartment crashes (the two most severe impact types) the median AIS, after

TABLE 3-3

AIS* DISTRIBUTION OF NONFATAL HOSPITALIZATIONS,

SIDE IMPACTS OF PRE-STANDARD 214 CARS,

BY IMPACT TYPE, NCSS

AIS Rating of Worst Injury	Percent of Cases: In Single-Vehicle Crashes (N=133)	In Multivehicle Crashes (N=378)	Nearside Occupants in Multivehicle Compartment Impacts (N=116)
4 or 5	15	10	16
3	29	23	29
2	24	26	23
1	8	16	11
unknown	24	25	21

*Abbreviated Injury Scale [1] rating of most severe injury.

unknowns are excluded, is AIS 3. It could be said that "a nonfatal hospitalization is roughly equivalent to an AIS 3." Life-threatening injuries - AIS 4 or 5 - outnumber minor injuries (AIS 1) among the nonfatal hospitalizations.

In all types of multivehicle crashes, the nonfatal hospitalizations are, on the average, less severe than in the preceding categories. The median AIS is 2.

A rough estimate of the absolute numbers of life-threatening, but nonfatal, injuries can be obtained by applying the percentages of AIS 4 or 5 in Table 3-3 to the estimates of nonfatal hospitalizations (from Tables 3-1 and 3-2). It appears that the number of life-threatening nonfatal injuries is roughly the same as the number of fatalities -viz., about 3000 in single-vehicle and 5000 in multivehicle crashes.

3.2 Injury mechanisms and contributing factors - a literature review

Refer to Section 4.1 for a description of components of the side structure.

3.2.1 Injury mechanisms

The source of injury most frequently described in the literature is a nearside occupant's contact with the car's intruding side structure when it is struck in the compartment area by another car or a light truck. Essentially, the following sequence of events takes place: a car or light truck, travelling with impact velocity V, hits the occupant's car in the door area. The door provides relatively little resistance to the striking vehicle and, soon, it is moving at a velocity close to V relative to the remainder of the occupant's car and the occupant - it is now an "intruding" door structure. In some cases, the intruding door will contact the nearside occupant, at a velocity not much less than the striking car's impact speed, while the occupant is still stationary with respect to the remainder of his car. In other cases, momentum transfer from the striking to the struck vehicle has proceeded to the point where the occupant has begun to move relative to the undamaged parts of his car - nevertheless, even in these cases, the door is still moving faster than the rest of the occupant's car at the time the occupant makes contact. Later on in the crash sequence, the mass of the occupant's car will have slowed down the striking vehicle to a velocity far below V, as the striking and struck vehicles reach a common velocity and the door becomes stationary relative to the struck vehicle; but this happens too late, because the occupant already contacted the door long ago, while it was still moving at a high relative velocity.

In short, the velocity of the door/occupant contact was substantially higher than Delta V (the eventual velocity change of the entire struck vehicle) and not much lower than the striking vehicle's impact velocity. This, above all, is what makes side structure intrusion a safety hazard.

Some early studies that made reference to the velocity of intruding side structures include States and States [77] and Lister and Neilson [51]. Subsequently, intrusion was studied in crash tests, where the velocity-time history of various parts of the vehicle and a simulated occupant could be monitored in detail. The studies confirmed the reality of the injury mechanism described above [10], [36], [58], [78]. Additional testing by Kitamura et al [48] and Provensal and Stcherbatcheff [68] established a linear relationship between

- door intrusion velocity
- maximum intrusion depth (at certain points)

o dummy chest and lower body acceleration

-i.e., a correlation of intrusion depth and injury severity, all other factors being held equal. Cesari et al showed that a significant reduction of nearside occupant injury could be achieved in crash tests by equipping the struck vehicle with an intrusion-resistent shield [10].

There are many situations, however, where "intruding side structures" cannot be logically identified as the principal injury mechanism. A farside occupant will normally not contact the door until it has stopped moving relative to the undamaged portions of the car. Intrusion is absent or of limited importance in impacts that are wholly or primarily outside the passenger compartment. In a fixed object collision that brings the car to a full stop, impact velocity and Delta V are the same, so the velocity of door/occupant contact cannot exceed Delta V. Thus, the situation where door intrusion is really important is the nearside occupant in a multivehicle crash with damage centered on the compartment. This is why that group of occupants is singled out for special attention throughout the evaluation.

Moreover, even for that group of persons, door intrusion is much less likely to affect head injury risk than chest and, especially, pelvis and leg injury - as was shown in crash tests [10], [48] and accident analyses [13].

The second major injury mechanism that must be considered is head injury - due to a wide variety of contact sources within the vehicle. generally unrelated to side structure intrusion. The high incidence of head injuries was apparent to those who studied accident data [6], [9]. States specifically identified head injuries due to contact with door window glass and the frontal interior of the car (windshield, dashboard, etc.) [77]. Mehta et al showed the predominance of head injuries as a cause of death on the General Motors file [57]; Hartemann et al found them to be predominant among AIS <4 injuries in France [36]. In other words, head injuries are common at both high and low severity levels.

Occupant ejection is the third major source of injuries and, especially, fatalities [6]. Mehta et al found that 17 percent of the AIS ≥ 4 injuries in nonrollover side impacts on the General Motors file were ejectees; door ejection was the most common route [57]. Melvin found cases of partial ejection through windows [58].

There are numerous other injury sources in side impacts. Lister and Neilson observed that occupants might contact almost any part of the vehicle interior, because of the wide variety of principal direction of force and vehicle rotation in side impacts [51]. Moreover, in an oblique crash, occupants may rebound from the side structure and contact frontal surfaces (such as the steering wheel). States [77] and Mehta [57] found that some of the most serious injuries are due to actual contact with the impacting vehicle or object, either because the side window shattered or because of a complete opening in the side structure.

Even when side structure intrusion is not a major contributing factor (i.e., in impacts not centered on the compartment or in the case of farside occupants), contact with the side structure can produce serious injury if the crash is sufficiently severe.

The side interior surface contains protrusions which, to a greater or lesser degree, may cause serious injury when contacted by occupants: armrests, hardware such as window cranks, the pillars, window frames and roof side rails.

Finally, noncontact injuries to the neck and back (resembling whiplash) may require hospitalization and in some cases fatally injure the spinal cord.

3.2.2 Contributing factors

The obvious reason why impacts to the passenger compartment are more likely to result in serious injuries than, say, frontal or rear impacts of the same velocity is that the principal structure between the occupants and the impacting vehicle or object - the door - is neither strong nor deep (relative to frontal and rear structures of a car) [18], [58].

In addition to being not very strong by itself, the door does not adequately transmit the impacting force to the strong part of the side structure: the sill, pillars and roof rails. Above all, forces in multivehicle crashes are not adequately transmitted to the sill, which is the most crush resistant part of the side structure, because the striking vehicle's frontal structure often overrides the sill without significant engagement. The critical importance of sill override was repeatedly stressed at the 8th conference on experimental safety vehicles [41], [48], [68] as well as other conferences [30], [31], [35]. Pillars and roof rails also absorb insufficient energy, especially in cars of hardtop and/or unitized design [51], [77]. The seating systems of most current vehicles do not act as load-bearing structures in side impacts [51].

The preceding factors may be called "structural" or "energy management" problems. The remaining factors pertain to "occupant packaging." It is widely felt that the side interior surface of existing vehicles does not contain sufficient padding to prevent serious injury in many crashes of relatively low severity and with little or no intrusion [13], [30], [35]. Side windows are criticized for shattering easily and not restraining or cushioning the occupant's head in the manner of a High Penetration Resistant windshield [58], [76], [77]. Safety belts are not necessarily designed with a view toward side impact protection and, specifically, are not designed to protect occupants from an intruding door [51], [58]. (Note, however, that safety belts were found to be effective in statistical analyses of side impact accident data [72].) Finally, deformation of the side interior surface as a result of crash damage can make this surface even more hostile to the occupants [51].

3.3 Statistical assessment of injury mechanisms

Data on the contact points and body regions of injuries on the NCSS, FARS and General Motors files allow a quantitative assessment of the relative magnitudes of the injury mechanisms described in Section 3.2.1.

3.3.1 Contact sources of serious injuries

Table 3-4 shows the distribution of specific injury contact sources in pre-Standard 214 cars on NCSS that resulted in fatality or hospitalization. One or more injuries may be included for each person who was killed or hospitalized: an injury is included if it is one of that person's 3 most severe injuries and is rated AIS ≥ 3 or has the same AIS as the most severe injury (see Section 10.2.1 for more details). The table includes

TABLE 3-4

CONTACT SOURCES OF SERIOUS* INJURIES,

SIDE IMPACTS OF PRE-STANDARD 214 CARS,

BY IMPACT TYPE, NCSS

Contact Source	NCSS Codes	Percent of Serious* Injuries: In Single-Vehicle Crashes (N=200)	In Multi-Vehicle Crashes (N=492)	Nearside Occ. in Multiveh. Compartment Impacts (N=181)
Instrument Panel	1	10	9	3
Steering Assembly	2	12	12	8
Windshield	3	6	2	1
Other frontal	4 - 14	6	5	2
Subtotal: frontal surfaces		34	28	14
Side interior surface (general)	15	26	33	53
Armrests, hardware	16,17,22	3	8	13
Pillars	18 - 21	5	3	4
Window glass	23	5	5	5
Window frame, roof rail	24,32	3	3	3
Subtotal: side surfaces		42	52	78
Other interior components	25,33 - 42	2	6	2
Exterior to car	43 - 49	16	5	3
Occupants, cargo	30 - 31	-	1	-
Noncontact injury	90	6	7	3

*Resulting in fatality or hospitalization; up to 3 injuries per person may be included distributions for single vehicle crashes, multivehicle crashes and for nearside occupants in multivehicle compartment impacts. As noted earlier, rollovers have been excluded.

Contacts with objects on the side interior of the vehicle account for 42 percent of the serious injuries in single vehicle crashes - a plurality but not a majority. Components on the front interior of the car (steering wheel, windshield, etc.) are almost as frequent, accounting for 34 percent of the injuries. Exterior objects (mostly ejection but also some objects that penetrate into the car) are the source of 16 percent of the injuries.

The most frequent individual NCSS contact code in single vehicle crashes is "side interior surface": a broad contact of the occupant's body with the door area, not restricted to any specific component. It caused 26 percent of the injuries. More concentrated contacts with individual components on the side - armrests, hardware, pillars, window glass, window frames and railings - added up to 16 percent of the casualties. So did the exterior contacts.

In multivehicle crashes, side surfaces account for a slim majority of the injuries - 52 percent. Frontal contacts are about as important (28 percent) as in single vehicle crashes but exterior objects are much less important (5 percent). In fact, exterior objects are less common as an injury source than noncontact injury (7%).

Again, "side interior surface" is the most common individual code, with 33 percent of the injuries. Eight percent of the casualties are specifically traced to the armrest or door hardware.

For nearside occupants in multivehicle compartment crashes, the overwhelming majority (78 percent) of injuries involve contact with side surfaces. Frontal contacts account for 14 percent of the injuries and exterior objects, 3 percent.

A single code, "side interior surface," accounts for more than half of the injuries (53 percent). Armrests and hardware (13 percent) are nearly as important as all frontal contact points, combined.

Table 3-4 shows that, even though side surfaces rank no. 1, frontal components are an extremely common injury source in all types of side impacts, especially single vehicle crashes. Ejection is more often a problem in single vehicle crashes than in multivehicle crashes. Contacts with individual, possibly hostile components including armrests, hardware, window glass, pillars, window frames and roof rails each account for a share of the serious injuries. Noncontact injuries (such as whiplash) are also found among the serious casualties. The substantial numbers of side contact casualties in crash modes other than nearside-multivehicle-compartment impacts show that serious injuries can result from these contacts even when intrusion is not an important factor. Thus, all of the injury mechanisms discussed in Section 3.2.1 seem to be represented in Table 3-4.

3.3.2 Body region and contact source of serious injuries

Table 3-5 retains the four broad categories of contact sources employed in Table 3-4 - frontal, side, exterior, other - and further subdivides the injuries in the first two categories by body region.

TABLE 3-5

CONTACT SOURCE AND BODY REGION OF SERIOUS* INJURIES, SIDE IMPACTS OF PRE-STANDARD 214 CARS, BY IMPACT TYPE, NCSS

Contact Source	Body Region	Percent of Serious* Injuries		
		In Single-Vehicle Crashes (N = 200)	In Multi-Vehicle Crashes (N = 492)	Nearside Occ. In Multiveh. Compartment Crashes (N = 181)
Frontal interior surfaces				
	Head, face, neck	12	9	2
	Chest, arms	12	12	7
	Lower body	10	7	5
Side surfaces				
	Head, face, neck	15	13	14
	Chest, arms	12	23	33
	Lower body	15	16	31
Exterior to car		16	5	3
Other		8	14	5

*Resulting in fatality or hospitalization; up to 3 injuries per person may be included.

Three body regions are defined:

- o head, face and neck
- o chest, arms, shoulders
- o lower body: abdomen, pelvis, legs

For nearside occupants in multivehicle compartment crashes, 64 percent of the serious injuries involve chest or lower body contact with side surfaces. This, specifically, is the group of injuries where side structure intrusion is most likely to have been an important factor. In Table 3-2, it was shown that 27 percent (i.e., 19,700 out of 73,600) of side impact fatalities and hospitalizations were nearside occupants in multivehicle compartment crashes. If, in turn, 64 percent of their injuries were significantly influenced by side structure intrusion, it means that 17 percent of all side impact injuries (i.e., 64% of 27%) are strongly influenced by side structure intrusion. In other words, 83 percent of the casualties are apparently not too strongly influenced by the degree of intrusion. Thus, Table 3-5 confirms that intrusion is one of the most important injury mechanisms in side impacts, yet at the same time sets a limitation on its importance.

Table 3-5 shows that head injuries account for substantial proportions of the serious injuries in side impacts. Head injuries from side surface contacts, alone, are 15 percent of all serious injuries in single vehicle crashes and 13 percent in multivehicle crashes. There are almost equally large numbers of head injuries due to frontal contacts.

3.3.3 Body region and contact source of fatal and life-threatening injuries

Table 3-6 shows the distribution, by contact source and body region, of fatal lesions and of life-threatening (AIS 4-5) nonfatal lesions. It uses

TABLE 3-6

CONTACT SOURCE AND BODY REGION OF FATAL AND LIFE-THREATENING INJURIES, SIDE IMPACTS, POST-STANDARD 214 CARS

(Based on General Motors and FARS accident data)

Contact Source	Body Region	Percent of Fatalities	Percent of Nonfatal AIS 4-5 Injuries
Frontal interior surfaces			
	Head	6	7
	Torso, legs	5	10
Side surfaces			
	Head	26	16
	Torso, legs	25	39
Ejection		17	17
Exterior object (nonejection)		12	5
Other		9	6

almost the same format as Table 3-5 (hospitalizations). The percentages in Table 3-6, which are for all types of side impacts combined, should be compared to an average of the first two columns of Table 3-5 (single and multivehicle crashes).

The percentage of life-threatening injuries due to contact with side interior surfaces (55) is not too different from the percentage of hospitalizations due to that source. Moreover, 39 percent of the life-threatening casualties are torso casualties due to side surface contact; 16 percent are head injuries. This is about the same ratio of torso to head injuries as in the hospitalizations due to side surface contact. A relatively larger portion of life-threatening injuries, than of hospitalizations, is due to ejection (17%) and penetrating exterior objects (5%). A relatively smaller percentage is due to frontal and other contacts. Still, by and large, the distribution of life-threatening injuries is close to that of all hospitalizing casualties.

The fatality distribution presents some contrasts. The majority of fatal lesions due to side surface contact are head injuries (26 out of 51 percent). Exterior objects entering the passenger compartment are a major source of fatal injuries (12%). Many of these lesions are also head injuries involving motion to the side. Torso and leg injuries due to contact with side surfaces - the type of injury most likely to be reduced by strengthening the side structure - account for just 25 percent of fatalities.

Table 3-6 was based primarily on Figures 12, 31 and 32 of Mehta's analysis of General Motors' accident data [57]. Figure 12 indicates that 17 percent of AIS 4-6 injuries in nonrollover side impacts are due to ejection.

FARS indicates a similar percentage for fatalities alone, so the 17 percent figure was used for both fatals and AIS 4-5 in Table 3-6. The remaining 83 percent of casualties were subdivided according to the percentages in Figures 31 and 32 (but excluding the "other" and "unknown" categories in Figure 32). Mehta had approximately 100 fatalities and AIS 4-5 injuries, each, with known contact source and body region, which is a larger sample than NCSS. The GM cases, however, are almost all post-Standard 214 cars, whereas all other tables in this chapter are based on pre-standard cars.

3.4 Statistical analysis of factors contributing to injury risk

The NCSS injury rates and distributions presented here are a companion to the discussion of contributing factors in Section 3.2.2.

3.4.1 Number of vehicles in the accident, occupant location and impact site

Table 3-7, which is based on tabulations of occupants of pre-Standard 214 cars on NCSS, shows that single-vehicle side impacts, when they occur, are about twice as likely to result in serious injuries as multivehicle side impacts. Nearside occupants in impacts centered on the compartment are nearly 3 times as likely to be seriously injured as nearside occupants in other impacts or farside occupants. This ratio holds true in both single and multivehicle crashes and demonstrates the extreme vulnerability of persons seated adjacent to a deforming side structure.

Since the less risky impact modes (noncompartment crashes, farside occupants) are more common (as indicated by N of persons in Table 3-7), they account for relatively high proportions of all casualties despite their lower injury rates (see Table 3-2).

TABLE 3-7

INJURY* RATES IN SIDE IMPACTS OF PRE-STANDARD 214 CARS, BY NUMBER OF VEHICLES IN THE ACCIDENT, OCCUPANT LOCATION AND IMPACT SITE, NCSS

	N of Persons	Percent Killed or Hospitalized
In single-vehicle crashes		
Nearside occupants - damage centered on compartment	233	27.5
Nearside occupants - damage not centered on compartment	307	9.8
Farside occupants	653	12.9
In multivehicle crashes		
Nearside occupants - damage centered on compartment	1044	14.7
Nearside occupants - damage not centered on compartment	2044	4.6
Farside occupants	3488	5.9

*Fatal or hospitalizing

3.4.2 Delta V

Figure 3-1 shows the cumulative distribution, by Delta V (velocity change of the struck vehicle), of serious injuries in side impacts of pre-Standard 214 cars on NCSS. Four distribution curves are shown:

- o in single vehicle crashes
- o in multivehicle crashes
- o nearside occupants in single vehicle compartment crashes
- o nearside occupants in multivehicle compartment crashes

It is apparent from Figure 3-1 that the 4 curves are nearly identical, except that a slightly higher percentage of the single vehicle casualties occur at low speeds. The location of the occupant or impact has little effect on the cumulative distributions. This does not mean that impact type has no effect on injury risk but rather that the differences in crash exposure have cancelled out the differences in injury risk.

The median Delta V of fatalities and hospitalizations is about 17 mph in single vehicle side impacts and 18 mph in multivehicle crashes. The 25th percentile is 10 mph in the single vehicle crashes and 13 mph for multi-vehicle. The 75th percentile of Delta V is close to 25 mph for all 4 crash types.

It should be noted that in multivehicle crashes and glancing fixed object collisions the closing speed is often considerably higher than Delta V. For example, a Delta V of 18 mph (median speed for serious injuries in multivehicle crashes) could have resulted from a 35 mph impact of a car into the middle of a stationary car of the same size, at a 90 degree angle.

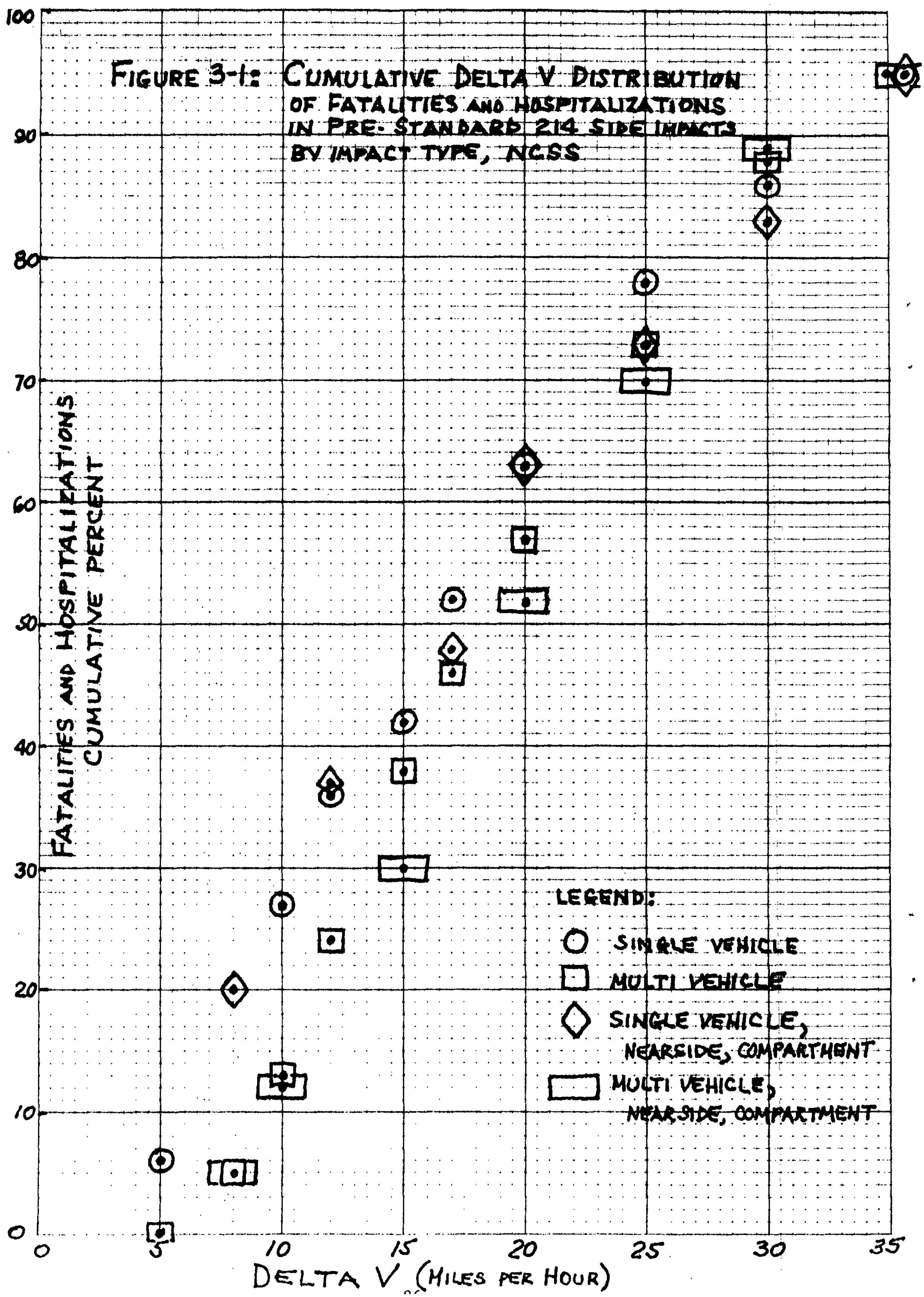

FIGURE 3-1: CUMULATIVE DELTA V DISTRIBUTION OF FATALITIES AND HOSPITALIZATIONS IN PRE-STANDARD 214 SIDE IMPACTS BY IMPACT TYPE, NCSS

Table 3-8 shows the injury rate as a function of Delta V for the same 4 crash types. At Delta V less than or equal to 10 mph, nearside occupants in compartment impacts are 2-3 times more vulnerable than the average occupant and single vehicle crashes carry far higher injury risk than multivehicle. At Delta V greater than 20 mph, both of these differences vanish.

3.4.3 Crush depth

Figure 3-2 shows the cumulative distributions, by crush depth, of serious injuries in side impacts of pre-Standard 214 cars on NCSS. Four distribution curves are shown:

- o in single vehicle crashes
- o in multivehicle crashes
- o nearside occupants in single vehicle compartment crashes
- o nearside occupants in multivehicle compartment crashes

The "crush depth" is the maximum of the 6 crush measurements obtained by NCSS investigators as input to the program for estimating Delta V (see Section 9.2).

The cumulative distribution curves for multivehicle crashes are slightly steeper than those for single vehicle crashes; the curves intersect at about 13 inches crush and from that point onwards, the multivehicle curves are above the single vehicle curves. The location of the occupant or impact does not seem to have a large or consistent effect on the cumulative distributions.

The median crush depth for fatalities and hospitalizations is about 16 inches in multivehicle crashes and 18-20 inches in single vehicle crashes;

TABLE 3-8

INJURY* RATES IN SIDE IMPACTS OF PRE-STANDARD 214 CARS, BY DELTA V AND IMPACT TYPE, NCSS

	Percent of Occupants Killed or Hospitalized		
	Delta V 1-10 mph	Delta V 11-20 mph	Delta V 21 + mph
All single vehicle crashes	9	20	40
Single vehicle: nearside occ. in compartment crashes	19	57	47
All multivehicle crashes	2	9	40
Multivehicle: nearside occ. in compartment crashes	7	13	47

*Fatal or hospitalizing

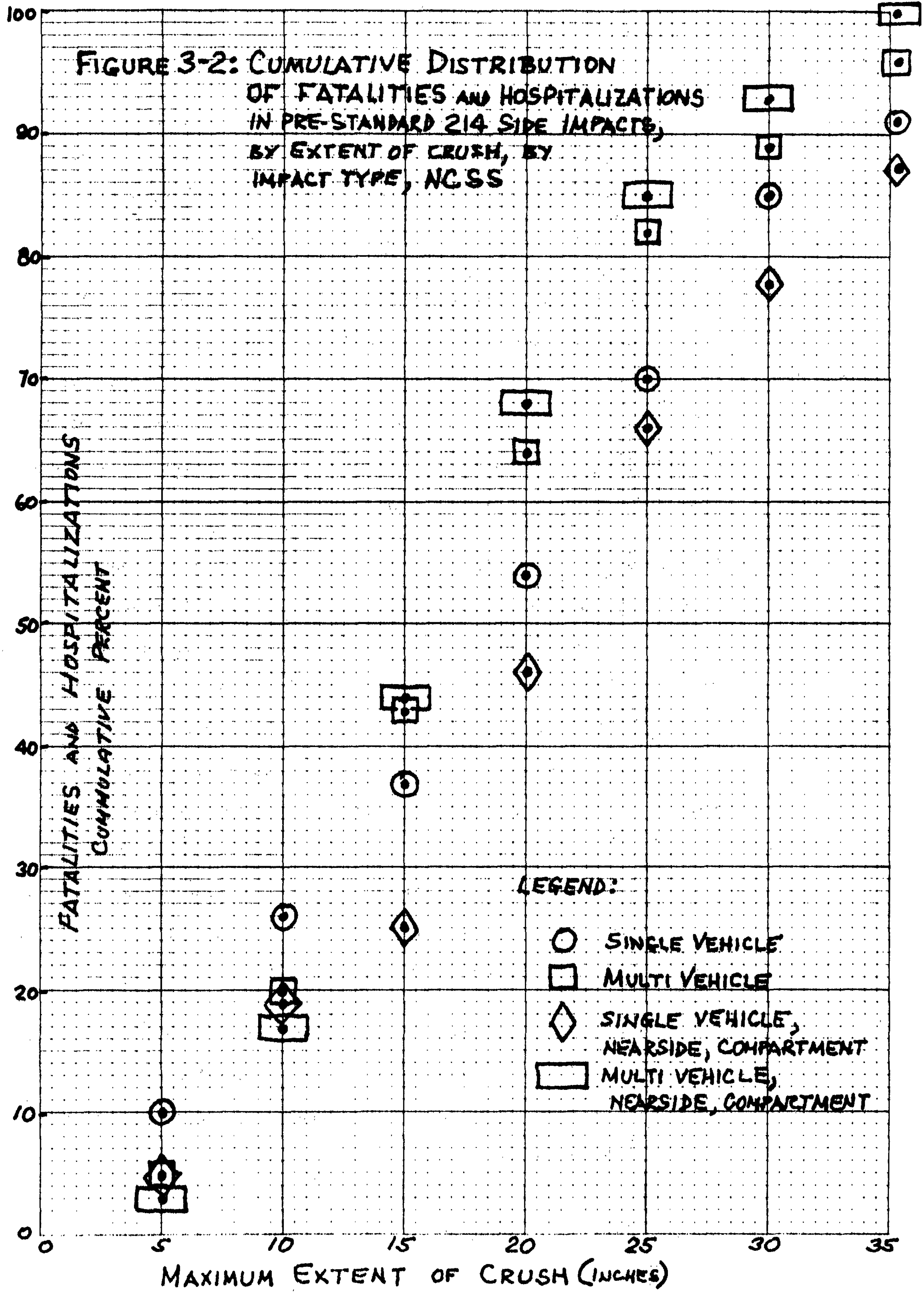
FIGURE 3-2: CUMULATIVE DISTRIBUTION OF FATALITIES AND HOSPITALIZATIONS IN PRE-STANDARD 214 SIDE IMPACTS, BY EXTENT OF CRUSH, BY IMPACT TYPE, NCSS
FATALITIES AND HOSPITALIZATIONS
CUMMULATIVE PERCENT
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
MAXIMUM EXTENT OF CRUSH (INCHES)
LEGEND:
SINGLE VEHICLE
MULTI VEHICLE
SINGLE VEHICLE, NEARSIDE, COMPARTMENT
MULTI VEHICLE, NEARSIDE, COMPARTMENT

the 25th percentile is 12 inches in multivehicle and 10 inches in single; the 75th percentile is 22 inches in multi and 27 inches in single vehicle crashes - i.e., the curves cross between the 25th percentile and the median.

One reason that the curves for single vehicle crashes are relatively level at high speeds is that depth of crush is not necessarily a good indicator of crash severity. A narrow, rigid fixed object such as a pole or tree can slice very deep into the passenger compartment without excessive velocity change to the vehicle and even without excessive danger to occupants who are not directly in the object's path.

Table 3-9 shows the injury rate as a function of crush depth for the same 4 crash types. In cars with 10 inches or less crush, nearside occupants in compartment impacts are twice as vulnerable as the average occupant and single vehicle crashes carry 2-3 times as high an injury risk as multi-vehicle. As crush depth increases, the discrepancy between single vehicle and multivehicle crashes decrease. In single vehicle crashes, the difference between nearside occupants in compartment impacts and other occupants also vanishes. But in multivehicle crashes, nearside occupants in compartment crashes are more vulnerable than others at all levels of crush. In fact, when crush is greater than 20 inches, nearside occupants in multivehicle compartment crashes have the highest injury rate of any group.

In short, for nearside occupants in multivehicle compartment impacts on the highway, there is an extremely strong relationship of crush depth to injury risk, consistent with experimental findings using staged crashes and anthropomorphic dummies [48].

TABLE 3-9

INJURY RATES IN SIDE IMPACTS OF PRE-STANDARD 214 CARS, BY EXTENT OF CRUSH AND IMPACT TYPE, NCSS

	Percent of Occupants Killed or Hospitalized		
	1-10 Inches Crush	11-20 Inches Crush	21 + Inches Crush
All single vehicle crashes	7	14	39
Single vehicle: nearside occupants in compartment crashes	12	32	39
All multivehicle crashes	2	8	30
Multivehicle: nearside occupants in compartment crashes	5	17	50

*Fatal or hospitalizing

3.4.4 Sill override in multivehicle crashes

The NCSS cases collected before April 1978 (about 55 percent of the NCSS file) contain information on whether sill override occurred in multivehicle crashes. (As noted in Section 3.2.2, sill override occurs almost exclusively in multivehicle crashes and is considered a major severity-increasing factor.) Sill override was found on 13 percent of the pre-Standard 214 cars among those NCSS cases; 20 percent of the persons killed or hospitalized in multivehicle side impacts were in cars with sill override. That overrepresentation of serious injuries is, however, not necessarily attributable to sill override: presumably, override is more likely to occur if the impact is centered on the compartment or under other crash conditions (e.g., higher impact speed) that could be associated with higher injury risk.

The best measure of increased risk attributable to sill override comes from crash testing. Hollowell and Pavlick, Kitamura et al and Provensal and Stcherbatcheff conducted pairs of crash tests in which conditions were identical except for sill override - which was prevented in one of the tests by raising the sill to ground height of the struck car or lowering the bumper height of the striking vehicle [41], [48], [68]. In general, the tests indicated a 5 inch reduction of crush (e.g., from 16 to 11 inches) when sill override was eliminated.

3.4.5 Type of object or vehicle contacted

Table 3-10 shows the distribution of single vehicle side impact fatalities by type of object contacted by the car during the crash. It is based on fatalities in cars of the last 2 model years without beams in 1975-81 FARS files.

TABLE 3-10

TYPE OF OBJECT CONTACTED IN PRE-STANDARD 214* SINGLE VEHICLE SIDE IMPACT FATALITIES, FARS 1975-1981

Type of Object Contacted	Percent of Fatalities**		
	Including All Deaths	Excluding Noncollisions	Excluding Non-collisions & Trains
Trees	33	36	41
Poles	26	28	32
Walls, buildings, underpasses	5	5	6
Guard rails	5	6	7
Embankments, culverts, ditches	10	11	12
Moveable objects, incl. fences	2	2	2
Trains	11	12	-
Noncollisions (mainly rollovers) with primary side damage	8	-	-

*Last 2 model years without beams

**N = 2427 fatalities

Trees (33%) and poles (26%) together account for 59 percent of the fatalities. Next are collisions with trains (11%), contacts with low fixed objects such as embankments, culverts and ditches (10%) and non-collisions - mainly rollovers - classified as side impacts based on their damage location (8%). Walls and buildings (5%) and guard rails (5%) account for most of the remaining fatalities.

Throughout this report, noncollisions have been excluded from NCSS analyses. The FARS data can be made comparable to NCSS by excluding them as well. After they are excluded, the percentage of fatalities due to collisions with poles or trees rises to 64 and, due to collisions with trains, 12 (see the middle column of Table 3-10).

Obviously, grade crossing accidents play a significant role in the side impact fatality problem. Throughout this report, they have been classified as "single vehicle" crashes because they involve only one highway vehicle. If they are excluded from the definition of single-vehicle crashes, the percent of fatalities due to trees or poles rises to 73.

The distribution of serious injuries (fatalities and hospitalizations) in single-vehicle side impacts on NCSS is shown in Table 3-11. It is remarkably similar to the fatality distribution. Trees (40%) and poles (36%) account for 76 percent of the serious injuries - nearly the same percentage as of fatalities. The main difference is that collisions with trains play a smaller role (in fact, no serious injuries in pre-standard cars on NCSS). That is hardly surprising, considering that grade-crossing accidents are extremely severe in comparison to most other types. Also, collisions with moveable objects

TABLE 3-11

TYPE OF OBJECT CONTACTED IN PRE-STANDARD 214 SINGLE VEHICLE SIDE IMPACT FATALITIES AND HOSPITALIZATIONS, NCSS

Type of Object Contacted	Percent of Fatalities and Hospitalizations*
Large trees	40
Poles	36
Buildings	3
Guard rails	10
Embankments, culverts, ditches	6
Moveable objects incl. fences, small trees	5
Trains	0

*N = 187 casualties

account for a higher percentage of serious injuries (5%) than fatalities (2%) - again, not surprising. Collisions with embankments, culverts and ditches - characteristic of complex off-road excursions - are less frequent among serious injuries (6%) than fatalities (11%).

Table 3-12 shows the distribution of serious injuries in pre-Standard 214 cars in multivehicle crashes on NCSS, according to the size/type of the striking vehicle. In 19 percent of the fatalities and hospitalizations in cars struck in the side, the striking vehicle was a subcompact or compact car. In 51 percent of the cases it was an intermediate or full-sized car. Thus, the striking vehicle was another car in 70 percent of the serious injuries. It was a light truck in 18 percent of the serious casualties; it was a heavy truck, tractor-trailer or bus in the remaining 12 percent.

The distribution of striking vehicles was virtually identical for nearside occupants who were seriously injured in compartment impacts.

TABLE 3-12

TYPE OF STRIKING VEHICLE IN PRE-STANDARD 214 MULTIVEHICLE SIDE IMPACT FATALITIES AND HOSPITALIZATIONS, NCSS

	Percent of Fatalities and Hospitalizations among	
Type of Striking Vehicle	All Multivehicle Side Impacts*	Nearside Occupants in Multiveh. Compartment Impacts**
Subcompact or compact car	19	22
Intermediate or full-sized car	51	51
Light truck, van, etc.	18	16
Heavy truck, tractor-trailer, bus, etc.	12	11

*N = 424 casualties

**N = 134 casualties

CHAPTER 4

STANDARD 214 AND OTHER IMPROVEMENTS IN SIDE IMPACT PROTECTION

Standard 214 establishes crush resistance requirements for the doors of passenger cars during a static crush test. The principal modification of cars performed in response to Standard 214 was the installation of door beams. The beams had been developed by the motor vehicle industry and were installed in many cars before the standard's January 1973 effective date. Five hypotheses on why beams might be effective are discussed in this chapter and the performance of beams in staged crashes is reviewed. There were a number of vehicle modifications other than Standard 214 which may have reduced side impact injury risk but, as will be shown, the modifications were typically carried out several years earlier, or later, than the installation of beams.

4.1 Elements of the side structure

The major components of the side structure in the passenger compartment area of a car are the door sill, the pillars, the roof rails and the door(s).

The door sill is the lower edge of the side structure and the outer edge of the car's floor. In a car of body-and-frame design, the floor is bolted to the car's frame just inside the sill, making that area an extremely rigid structure. In a car of unitized construction, although there is no frame beneath the passenger compartment, the sill area of the body is also made more rigid than any other part of the side structure.

The pillars are the strong vertical elements of the side structure. The A-pillar is located in front of the front door and runs from the floor to the roof. The C-pillar is located immediately behind the rear door in a 4-door car or behind the rear window area in a 2-door car; it also runs from the floor to the roof. The B-pillar is located immediately behind the front door. In a genuine hardtop car, the B-pillar runs only from the floor to the bottom of the windows, not to the roof. In a sedan or "pillared hardtop," it runs all the way to the roof. (Caution: the terms "hardtop" and "sedan" are used loosely in the trade.) The roof rails are the strong upper element of the side structure.

The doors are the sheet metal elements that cover the side structure. They are attached to the pillars by hinges at the front and latches and strikers at the rear. The upper part of the door contains a window and may have a light frame or no frame at all around the window. Prior to Standard 214, doors generally did not contain a significant internal reinforcing structure.

4.2 Development and implementation of Standard 214

4.2.1 Developments that preceded regulation

During the 1960's, the Fisher Body Division of General Motors conducted research and testing to improve side impact protection. They discovered two courses of action that significantly improved protection, as evidenced by reductions of intrusion and dummy acceleration levels in crash tests. The first was to raise the sill high enough to eliminate override by a striking vehicle. This approach was rejected because it would have necessitated customers to step over a high sill when entering and leaving a car. The second method was to increase the structural strength of components other than the sill. Hedeen and Campbell developed a beam which they installed inside the door. Initially, they supplemented the beam with massive enlargements to pillars and other components and obtained significantly better performance in crash tests. Their next step was to investigate whether similar performance could be obtained with a less massive upgrade. They achieved satisfactory results with just the door beam and a local reinforcement of the B pillar at the floor level (plus the improved door latches and hinges that had been standard equipment since 1965). The door beams and local B-pillar reinforcements were then installed in 1969 model GM full-sized cars [39]. Hedeen and Campbell's explanations of their success are discussed in Section 4.3.

A static test procedure for side door strength was desired because it would be simpler and more repeatable than full scale crash testing. Such a procedure was developed at Fisher Body Division and became SAE Recommended Practice J367 in March 1970 [39], [62]. It describes how a door is to be crushed by an impactor device and how forces are to be measured, but it does not specify a minimum acceptable load. Although the door is not removed from the car prior to performing the test, the procedure is designed to minimize interaction with structures other than the door itself. The impactor is located so as to avoid any contact with sills, pillars or roof rails; the seats and steering column are removed from the car before the test. The controversy aroused by this approach is discussed in Sections 4.2.2 and 4.3.

4.2.2 Regulatory history

NHTSA initially planned to address the problem of side impact protection with a Consumer Information Standard -- i.e., it would publish ratings of passenger cars' side door strength rather than mandate a minimum acceptable strength level. An Advance Notice of Proposed Rulemaking was published in October 1968, requesting information on methods to measure side intrusion protection [18]. It was followed in December 1968 by a Notice of Proposed Rulemaking, titled "Side Intrusion Protection" [19]. The NPRM defined a static crush test similar to the one later used in Standard 214 and stated that NHTSA would publish the average force needed to crush a door to a point 12 inches outboard of the center of the adjacent seat position.

The ANPRM and NPRM elicited 123 letters to the docket. General Motors stated that its door beams reduced intrusion in dynamic tests [3]. On the other hand, letters from manufacturers suggested that door strength, alone, is not necessarily a good measure of intrusion protection [4], [52], [79]; that the proposed static test did nothing to motivate improvements in padding or measures to prevent sill override [52], [53]; and that the test unduly favors 4-door cars and sedans [79], inconsistent with accident data which showed no comparable safety benefit in actual crashes for these cars [31]. Dr. States pointed out that the proposed static test resembles neither a typical multivehicle nor single vehicle side impact crash [75]. Finally, Renault felt that the performance measure was prejudicial against small cars (since it takes less crush to reach a point 12 inches outboard of the center of the adjacent seat position) [52].

NHTSA superseded that NPRM with another one in January 1970 [20]. The proposed regulation was renamed "Side Door Strength" in recognition of the limited scope of the test. Two changes were made to reduce the alleged prejudice against smaller cars: it was proposed to measure the force needed to produce 12 inches of crush from the outside (rather than to reach a point 12 inches from the center of the seat) and a weight correction factor was added. The first change was justified at that time on the grounds that "occupants are thrown against the door" rather than vice-versa and the second on the grounds that lighter vehicles are more easily displaced, limiting the intrusion that occurs before a common velocity is reached.

This NPRM, in turn, drew comments from manufacturers of large cars that the performance measure was biased in favor of small cars [16], [47], [80]. Chrysler submitted results of its crash tests on cars with and without beams -- the results are discussed in Section 4.3.2.

NHTSA reissued the NPRM in July 1970, removing the weight correction factor and making other minor changes [22]. Finally, in October 1970, NHTSA withdrew the proposed Consumer Information standard in favor of Federal Motor Vehicle Safety Standard 214 [24].

The NPRM for Standard 214 was issued in April 1970 [21], when the proposal for a Consumer Information Standard was still active. The NPRM for Standard 214 specified the same static crush test as the January 1970 consumer information NPRM [20], but now established 3 minimum crush resistance levels for side doors:

- Initial crush resistance: an average of at least 2500 pounds over the first 6 inches of crush

- Equivalent crush resistance: an average of at least 3750 pounds over the first 12 inches of crush (possibly diminished by a vehicle weight correction factor)

- Peak crush resistance: a peak (not average) of at least twice the vehicle's weight somewhere in the first 18 inches of crush.

The rationale for Standard 214 that was stated in the NPRM is discussed in Section 4.3.1. The proposed effective date for the standard was 9/1/71.

The letters that NHTSA received in response to the NPRM contained comments similar to those on the Consumer Information NPRM. In other words, the general thrust of the comments was that the static strength of, essentially, the door in isolation was not necessarily a good measure of the dynamic crush resistance of the whole vehicle side structure. Specifically, there were objections to the vehicle weight correction factor, the measurement of crush from the outside of the car, the vertical placement of the impactor and the removal of seats during the test. Since the impactor is always placed above the sill and the seats are removed, the proposed standard did not encourage the use of a raised sill or load-bearing seats.

The final rule for Standard 214 was issued in October 1970, at the same time that the Consumer Information NPRM was dropped [23]. The effective date for the standard was fixed at 1-1-73. In the final rule, vehicle weight correction factors for crush resistance were dropped and the other requirements modified as follows:

- Initial crush resistance: an average of at least 2250 pounds over the first 6 inches of crush
- Intermediate crush resistance: an average of at least 3500 pounds over the first 12 inches
- Peak crush resistance: a peak of at least 7000 pounds or twice the vehicle curb weight, whichever is less, somewhere in the first 18 inches

The final rule left unchanged the requirement that crush should be measured from the outside, stating that maximum benefits would be obtained if door strength were concentrated near the outside surface of the door. It also left unchanged the requirements concerning impactor location and seat removal, stating that a change in the requirements would interfere with the objective measurement of door strength. A petition for reconsideration on the issue of measuring crush from the inside was denied [25].

Standard 214 went into effect on January 1, 1973. In March 1980, Standard 214 was amended to allow a choice of performing the compliance test with the seats inside the vehicle (but having to meet higher force requirements) or removing the seats and meeting the 1973 requirements [26]. Since the post-Standard 214 vehicles studied in this report were built before the standard was amended, an analysis of the effects (if any) of the amendment on production vehicles is outside the scope of this evaluation.

4.2.3 Vehicle modifications in response to Standard 214

The principal vehicle modification in response to Standard 214 has been the side door beam. It is a metal bar of channel design, typically 8 inches wide and with channels 2 inches deep. It is located inside the door, close to the outside surface, about 10 inches above the sill. It runs the length of the door, being attached to the door frame vertical members at the hinge and latch ends of the door. All production vehicles of the 1973-82 era appear to have beams [26], conversely, there is no record of any vehicle that had beams and was unable to meet Standard 214. In some vehicles, the beam is accompanied by a beam cover, stiffener, and/or mounting flanges [37].

The only other modification specifically identified in the literature to be associated with the installation of beams is a local reinforcement of the B pillar at the floor level. Hedeen and Campbell state that such reinforcement was both necessary and adequate for the

B-pillar of full-sized 1969 GM cars to stand up under loads transmitted to it through the beam [39]. They also stated that no additional enlargement or reinforcement was necessary and that existing latches and hinges were adequate.

Chrysler commented that the static test for side door strength unduly favored cars with 4 doors and/or full B pillars [80]. Yet even 2-door hardtops met the requirements of Standard 214 after a beam was installed. There is no evidence of manufacturers shifting from hardtop to pillared construction in response to Standard 214; on the contrary, they typically continued producing hardtops for 2-3 years (or more) after beams were installed (see Section 4.4.2 and 4.4.3).

4.2.4 Implementation schedule

Beams were installed in many models before Standard 214's effective date of 1-1-73, beginning with full-sized GM cars in model year 1969. Table 4-1 shows the first model year (or date) in which beams were installed in domestic cars and Volkswagens. The information was obtained from the Motor Vehicle Manufacturers Association in 1981. The most important differences between Table 4-1 and comparable tables in earlier reports (e.g., [46], pp. 42-43) are that, according to Table 4-1:

- o Ford Pintos did not receive beams until 1973
- o Most Chryslers and VW's did not necessarily have beams for the full 1973 model year, but only for cars built after 1-1-73

TABLE 4-1

DOOR BEAM INSTALLATION DATES

(Source: Motor Vehicle Manufacturers Association, 1981)

Corporation	Model/Size Class	Model Year/Date Introduced
American Motors	Javelin, AMX	1971
	All others	1973
Chrysler	Barracuda, Challenger	1970
	All others	1/1/73
Ford	Full-size Ford, Mercury, Lincoln	1971
	Mustang, Cougar	1971
	Torino, Montego	1972
	Lincoln Mark series	1972
	Pinto	1973
	Maverick, Comet	1973
General Motors	Full-size (B and C Body)	1969
	Grand Prix	1969
	Intermediate (A Body)	1970
	Monte Carlo (A special - except Grand Prix)	1970
	Camaro, Firebird	mid 1970
	Toronado, Riviera, Eldorado	1971
	Vega	1971
	Nova	1973
	Corvette	1973
VW	Beetle	1/2/73

4.3 Discussion: why might Standard 214 be effective?

Section 4.3.1 presents 5 hypotheses on why Standard 214 might improve side structure performance in crashes. The hypotheses are stated not as facts but as conjectures. They are discussed in the light of engineering considerations, including a review of references to them in the literature. Section 4.3.2 is a review and discussion of staged crash test results.

4.3.1 Five hypotheses on effectiveness

Hypothesis 1: Crush Resistance In Section 3.2.1 it was reported that nearside occupants are vulnerable to injuries involving contact with the car's intruding door structure when it is struck in the door area by another vehicle. The occupant makes contact with the door at a time when it is moving (relative to the occupant and the remainder of the occupant's car) at a speed not much less than the initial impact speed of the striking vehicle. It is very desirable to significantly slow down the rate of door intrusion -- i.e., the speed of the striking vehicle -- before the occupant contacts the door. Theoretically, an increase in door strength due to Standard 214 should make at least some contribution to slowing down the striking vehicle, for the following reasons:

o The door itself, while being crushed, dissipates more of the kinetic energy of the striking vehicle, slowing it down more rapidly and in a shorter distance.

o There will be relatively more crumpling of the striking vehicle's front structure and relatively less collapse of the struck vehicle's door.

o Momentum will be more rapidly transferred from the striking vehicle to the struck vehicle. The sooner the vehicles reach a common velocity, the sooner the door stops moving relative to the rest of the struck vehicle.

o A door beam, loaded in tension by the striking vehicle, that effectively interfaces with the struck car's pillars will transmit loads to the pillars better than a soft, pre-Standard 214 door structure.

These mechanisms could be classified under the general concept of "crush resistance." They could be involved in any impact by another vehicle into the passenger compartment -- both 90 degree impacts and oblique ones.

Hypothesis 1 was the primary rationale for Standard 214 stated by NHTSA in the preamble to its NPRM [21]:

> "Recent studies demonstrate that in side impacts the percentage of dangerous and fatal injuries increases sharply as the maximum depth of penetration increases and that in fatal side collisions most occupants die from side structures collapsing inward on them rather than from their striking the door. To protect occupants from such hazards, a strong door structure is required, in conjunction with an effective restraint system and energy-absorbing materials on the vehicle's interior surfaces."

Hedeen and Campbell found that the beam helped reduce penetration in crash tests, specifically stating that deformation of the striking vehicle's front structure increased when the struck car had a beam [39]. Kitamura et al also observed that beams reduced intrusion [48].

On the other hand, Renault found no benefits for beams in 90 degree crash tests [5]. Chrysler, in their letters to the docket, questioned the validity of side door strength measurement because beams gave a very large increase in static strength without a comparable decrease of intrusion in dynamic crash tests. Nevertheless, Chrysler reported a reduction of intrusion (albeit a small one) in 90 degree tests [81].

There are two factors that, intuitively, limit the potential significance of hypothesis 1:

- In most crashes, the striking vehicle immediately or after a short time engages side structure components much stronger than the door: the sill and/or pillars. Most of the energy dissipation/momentum transfer is through these components.

- The door is so weak relative to the striking vehicle's front structure that even beams, at best, are only a small start to addressing the problem of strength imbalance.

Therefore, it is intuitively clear that beams will not produce a "miracle" reduction of intrusion in crashes proportional to the large increases in static door strength that they produce in the Standard 214 compliance test. Nevertheless, as Table 3-9 shows, the relationship between intrusion and injury risk is so strong for nearside occupants in multivehicle compartment crashes that even a modest reduction of intrusion (1-2 inches) could produce significant reductions of serious injury risk (10-20%).

Hypothesis 1 would appear to be relatively less important in essentially perpendicular side impacts with fixed objects such as poles or trees, partly because the initial door intrusion velocity (impact speed) is not so high relative to the eventual velocity change of the rest of the car (Delta V -- see Section 3.2.1). Also, the sill and roof rails are firmly engaged, whereas in multivehicle crashes they may not be engaged at all.

Hypothesis 2: Deflection of striking objects/vehicles In an oblique side impact, the beam acts somewhat like a highway guard rail to help partially deflect the striking vehicle or object. It helps the struck car "scrape by" -- i.e., it continues to move in a forward direction, relative to the striking vehicle or objects. The potential benefits of a deflecting action, which are not necessarily limited to nearside occupants, include the following:

o Damage becomes shallower and spread over a wider area -- i.e., a reduction in the depth and velocity of intrusion and of vehicle deceleration o Damage may spread out from the passenger compartment area to less vulnerable parts of the side structure outside the compartment area

o The struck vehicle and striking vehicle/object may disengage before achieving a common velocity rather than "hanging up" on one another -- i.e., a reduction of Delta V for the struck vehicle

o The integrity of side structure components -- hinges, latches, etc., -- may be easier to maintain as a result of the preceding changes in damage patterns.

Hedeen and Campbell mention deflective action as one of the primary reasons for the effectiveness of beams, as evidenced by their crash tests [39]. Renault reported that beams were effective in producing less penetration and a more glancing trajectory in oblique impacts [5]. More generally Rodger [73] and Greene [35] reported that one of the main benefits of side structure improvements is that they allow vehicles to glance apart in oblique crashes.

<u>Hypothesis 3: Sill Override Prevention</u> The beam is located relatively high inside the door, leaving a softer area in the gap between the beam and the sill. Under the right circumstances, the beam could initially hold the striking vehicle down, forcing it to penetrate into the

softer area below the beam. That, in turn, would increase the likelihood that the striking car would engage the sill rather than override it (see Section 3.2.2 about the importance of preventing sill override).

Hedeen and Campbell reported that beams were effective, in crash tests, in holding down the striking vehicle and promoting sill engagement [39]. Chrysler disputed the hypothesis and showed that a badly designed beam could actually encourage the striking vehicle to ramp over the sill [81].

Hypothesis 3 does not apply in crashes with fixed objects such as trees, since sill override cannot occur.

Hypothesis 4: Greenhouse Protection In a car without beams, the side structure has no strong component located above the sill, parallel and exterior to the sill. In a collision with a fixed object, the sill will firmly engage the object while the upper parts of the car will tend to slightly tip over into the object, increasing the object's penetration into the extremely vulnerable greenhouse area of the car. The beam provides a strong component parallel to the sill and helps keep the car more nearly upright in the crash.

This hypothetical effect does not appear to have been mentioned in the literature.

Hypothesis 5: Door Integrity Protection The beam helps the door maintain its basic shape during a crash, preventing it from being deformed to the point that it separates from hinges, latches or from the vehicle. Stresses on latch assemblies are reduced in a manner that prevents door opening in crashes. As a result, there are fewer occupant ejections through the door area.

The hypothetical effect may, in part, be a corollary of Hypotheses 1 and, especially 2: if damage is shallower in the compartment area and more readily spread out to other parts of the car, stresses to doors and components will be reduced.

Hypothesis 5 does not appear in previous reports but plays an important role in Chapter 9 of this evaluation.

4.3.2 Review of crash test results

Although many automobiles have been side impact tested during the past 20 years, there have been relatively few "pure" tests of Standard 214. A "pure" test of Standard 214 is one in which 2 cars, identical except that one complies with the standard and the other does not, are subjected to identical crash tests.

Hedeen and Campbell performed crash tests on pre-Standard 214 cars and on cars equipped with beams and a local B-pillar reinforcement at the floor level. As described earlier, the cars with beams had less penetration, because the beams imparted more deformation to the striking vehicle's frontal structure, partially deflected the striking vehicle, and held the striking vehicle down to force sill engagement (Hypotheses 1-3 of Section 4.3.1) [39].

Chrysler performed 3 pairs of identical crash tests on cars with and without beams [81]. In a 45 degree impact of a car into the side of a 2-door hardtop, the beam reduced penetration from 12.8 to 12 inches. In a 45 degree impact into a 4-door sedan, penetration was reduced from 8.8 to 8 inches. In a 90 degree impact to the sedan, intrusion was cut from 7 to 5.8 inches. These are reductions of 6, 9 and 17 percent, respectively, in the depth of intrusion.

Renault reported that beams were effective in reducing penetration and providing a more glancing trajectory in oblique impacts, but found no benefits in 90 degree impacts [5].

Calspan Corporation performed a side impact test under contract to NHTSA in 1969. It was not a "pure" test of Standard 214: one of the cars was pre-standard and the other had beams <u>and</u> a roll bar. In the test, the cars were mounted on casters and pushed into a pole at 90 degrees and 20 mph. The pre-standard car had 20.8 inches crush and the other 18.5 inches, but it is unknown how much of the reduction was due to the beams and how much to the roll bar [59]. Since this was a 90 degree and not an oblique impact, it cannot be considered a test of Hypothesis 2 (see Section 4.3.1).

Much more recently, Kitamura et al, performed a pure test of Standard 214. The struck vehicles were identical 2600 pound, 4-door post-Standard 214 sedans except that the beams were removed from the second car. The striking vehicle weighed 3600 pounds and the compartment was impacted at a 60 degree angle and 35 miles per hour. Beams reduced the depth of intrusion by 8 percent and, more importantly, reduced the nearside dummy's rib, thorax, shoulder and pelvis acceleration levels by amounts ranging from 20 to 35 percent [48]. This is strong evidence that beams are effective for nearside occupants when a car is impacted in the compartment by another car at a moderately high speed.

4.4 Side structure modifications other than Standard 214

The other Federal Motor Vehicle Safety Standards need to be reviewed as to whether they may have reduced injury risk in side impact crashes. If so, their benefits must be taken into account in this evaluation and should not be wrongly attributed to Standard 214. Side structure modifications not made in response to safety standards, but with possible safety implications, must likewise be reviewed. These reviews occupy Sections 4.4.1 and 4.4.2.

Specifically, this evaluation relies on FARS, NCSS and Texas accident data -- Chapters 6, 7 and 8 respectively -- for analyses of Standard 214 effectiveness. Some of the FARS and Texas analyses are based on comparisons of cars of the last model year before beam installation with those of the first beam-equipped model year. For these analyses, there is special concern with modifications that coincided with Standard 214 -- their effect would be confused with Standard 214's. But modifications that occurred one year or more before beam installation would not bias the analyses (since all cars in the analysis would have them) nor would changes that occurred one or more years after beams (since no cars would have them). Other FARS analyses and some of the NCSS analyses are based on the last two years without beams versus the first two with them. In these analyses, there is special concern not only with changes that coincided with beams but also with those that occurred one year before or after beam installation. Other NCSS analyses are based on five years before or after beam installation -- here the concern extends to changes up to four years before or after beam installation. Finally, some NCSS analyses include the full data set -- for these, the concern extends to the full range of model years well represented on NCSS, viz., 1965-78.

In short, the timing of other side structure modifications is important,-especially in relation to the timing of beam installation. As Table 4-1 showed, beams were first installed during 1969-1973½, depending on the make and model. Section 4.4.3 is a chronology of side structure modifications during 1965-78 by make and model, and a discussion of their timing relative to Standard 214.

Finally, Section 4.4.4 presents a few of the current research concepts for improving side impact protection.

4.4.1 Other safety standards

Standard 201 sets padding requirements for arm rests, which were the source of 6 percent of the serious injuries in side impacts (see Table 3-4). It requires padding of certain frontal interior surfaces, especially the dashboard, which also account for significant percentages of the serious injuries in side impacts. Standard 201 took effect on 1-1-68, but the General Accounting Office's report on the safety standards suggests that one-third of 1966 model cars complied with it, as did one-half of 1967 cars and all 1968 models [17]. Thus, the implementation of Standard 201 took place, on the average, 4 years before the installation of beams.

Standards 203 and 204 significantly reduced the risk of serious injuries resulting from contact with the steering assembly [44]. According to Table 3-4, the steering assembly accounts for 12 percent of the serious injuries in side impacts. Standards 203 and 204 took effect on 1-1-68, but, in fact, two-thirds of 1967 models and all 1968 cars were in compliance. Thus, the implementation of Standards 203 and 204 took place, on the average, 4 years before the installation of beams.

o Standard 205 regulates glazing materials used in windshields and other windows. The most important modification was the High Penetration Resistant windshield, but side windows may also have been modified. The windshield accounts for about 3 percent of serious side impact injuries and side windows, 5 percent. All 1966 model cars appear to meet the requirements of Standard 205 -- this is an average of 5 years before the installation of beams.

o Standard 206 sets requirements for door hinges, latches and locking systems, which are important components of the vehicle side structure (see Section 4.1). The standard incorporates SAE Recommended Practices J839b and J934a developed in 1965 [62] and it appears that the 1965 models met its requirements -- this is an average of 6 years before the installation of beams.

o Standards 208, 209 and 210 pertain to safety belts. Restraints provide a number of benefits in side impacts, such as preventing ejection, protecting farside occupants and preventing certain injuries due to contact with frontal interior surfaces or other components relatively far from the seat. During 1968-74, a number of changes were made in the safety belt requirements that led to an aggregate increase of occupant belt usage from 8 percent in all pre-Standard 214 cars to 11 percent in all post-standard cars on NCSS. There was, however, no increase in belt usage in cars of the first 2 model years with beams relative to the last 2 years without them (see Table 7-4).

o Standard 216 sets minimum strength requirements for passenger car roofs to reduce the likelihood of roof collapse in a rollover accident. In some makes and models, it led to thicker roof rails and/or pillars [32], thereby also strengthening the side structure. These modifications were made in the 1974 model year -- an average of 3 years after the installation of beams.

4.4.2 Vehicle modifications not mandated by safety standards

o Shift from genuine to pillared hardtops: the most noticeable change in the side structures of cars of the 1970's was the gradual replacement of genuine hardtops by cars with full B-pillars (see Section 4.1 for definitions). This shift was not performed in response to Standard 214; in almost all cases, it took place at least 2 years after beams were installed and, in most cases, some time after the standard's 1-1-73 effective date. The only exception was the Camaro/Firebird, where beams and full B-pillars were installed at the same time as part of a complete redesign. More typical cases are the GM intermediates and Chrysler compacts, where B-pillars were installed in all cars 3 years after beams; in the full-sized GM cars, hardtops were gradually eliminated 4-7 years after beams were installed. Moreover, the statistical results of Friedberg, et al [31] and Section 7.5 of this report suggest that the safety implications of installing full B-pillars are relatively small — at least, in comparison to the effects of Standard 214. For these 2 reasons -- timing and safety effects -- the bias on Standard 214 effectiveness estimates is small and easy to control for (see Section 7.5).

o Ford Torino and Mercury Montego changed from unitized to body-and-frame construction in 1972, the year that beams were installed. These models accounted for about 3 percent of car sales. All other models appear to have retained the same basic body structure (i.e., body-and-frame vs. unitized or integral) during the 1965-78 era.

o Convertibles gradually declined from 5 percent of sales to zero during 1965-78. The elimination of convertibles was not scheduled to coincide with the installation of beams, but took place gradually. Although the safety implications of discontinuing convertibles are obvious, the net effect on injury rates is minimal, since they were rare to begin with.

o Domestic subcompacts appeared in 1971, in the middle of the beam installation period. According to Table 4-1, Pintos were being produced for 2 years before beams were installed. Vegas, on the other hand, had beams from the start; they are removed from the FARS and Texas analyses to assure that comparable pre-standard cars exist for every post-standard car in the analyses.

o Major "downsizing" began with full-sized and intermediate GM cars in 1977 and 1978, respectively -- 8 years after beams were introduced. Also, the large-scale introduction of front-wheel drive took place after the accident data used in this report were collected.

o There were gradual weight increases within size classes during 1965-76. The increases from year to year were small, but for NCSS analyses covering wider ranges of model years, the weight differences must be accounted for by multivariate statistical procedures.

4.4.3 Chronology of side structure modifications and restyling

1965: Door latches and hinges meeting Standard 206

Major body change for full-size GM, Ford, Chrysler [83]

1966: HPR windshields (Standard 205)

Some padded dashboards (Standard 201)

Major body change for Ford, Chrysler intermediates

Restyling of some GM intermediates, Lincoln, Riviera

Toronado introduced

1967: EA steering column on GM, AMC, Chrysler (Standards 203-204)

Camaro, Firebird, Cougar and Eldorado were introduced

Compact cars were restyled -- industry-wide

1968: All cars meet Standards 201, 203 and 204

Shoulder harnesses for front outboard occupants (Standard 208)

GM intermediates restyled

Dodge Charger restyled

Lincoln Mark series introduced

1969: Beams on full-sized GM cars, Grand Prix

New bodies for full-sized Buick, Olds, Fords and Chryslers

New sheet metal for full-sized Chevy

Grand Prix, Maverick were introduced

1970: Beams on intermediate GM, Barracuda, Challenger

Beams on Camaro, Firebird (at midyear)

Monte Carlo, Cutlass Supreme were introduced and other GM intermediates restyled

Challenger was introduced and Barracuda restyled

Camaro, Firebird got major redesign and became pillared hardtops

Ford intermediates restyled

Gremlin was introduced

1971: Beams on full-sized Ford, Mercury, Lincoln

Beams on Mustang, Cougar, Javelin, Vega, Eldorado, Riviera, Toronado

Complete restyling of full-size and luxury-specialty GM and full-size Ford

Complete restyling of Mustang, Cougar, Satellite and Coronet

Vega and Pinto were introduced

Pillared hardtop available on Eldorado, Thunderbird

1972: Beams on Torino, Montego, Thunderbird, Lincoln Mark

Retracting seat belts

Major redesign of Torino and Montego, including change from unitized to body-and-frame construction

Thunderbird and Lincoln Mark got new chassis and sheet metal

Full-sized Chryslers got new sheet metal

1973: Beams on Ford compacts, Pinto, GM compacts, Corvette

Beams on AMC (except Javelin, which got them in 1971)

Beams on Chryslers by 1/1/73 (except Barracuda/Challenger in 1970)

Seat belt warning buzzer

GM intermediates got new bodies and changed to pillared hardtops

Full-sized Ford got new sheet metal

1974: Some roofs, roof rails and/or pillars modified in response to Standard 216

3 point belts with starter interlock

Pillared hardtops available on full-sized & intermediate Fords,
Electra, Riviera, Charger

Mustang is downsized and becomes a pillared hardtop

Cougar becomes an intermediate

1975: 3 point belts -- ignition interlock discontinued at midyear

Cordoba, Pacer, Monza, Seville introduced

Granada/Monarch introduced -- using Maverick/Comet wheelbase

Javelin, Ambassador dropped

Chrysler intermediates, GM compacts got new sheet metal

Pillared hardtops available on full-sized GM

Pillared hardtop standard on Cordoba, Gran Fury, Monaco

1976: Aspen, Volare replace Dart, Valiant; always have pillars

Chevette was introduced

1977: Major downsizing of full-sized GM, with pillars on all cars

Restyling of Ford intermediates - pillared hardtops available

Big Thunderbird dropped

1978: Major downsizing of intermediate GM

Fairmont/Zephyr replaces Maverick/Comet

Horizon/Omni (front-wheel-drive subcompacts) introduced

Genuine hardtop now available only on LTD II, Cougar, Lincoln Mark V
and Chrysler New Yorker

It is evident that the installation of beams did <u>not</u> coincide with other safety standards that significantly affect injury risk in side impacts. The fleetwide shift from genuine to pillared hardtops was a gradual process that, typically, took place several years after beams were installed. The only models that were introduced or very significantly redesigned at the time of beam installation were Camaro, Firebird, Vega, Torino and Montego. (Grand Prix, Monte Carlo and Cutlass Supreme, although "new" cars at the time beams were installed, were reasonably similar to earlier GM intermediate 2-door hardtops.)

It is true that beams were installed in many models at the time of a body changeover (e.g., full-sized Buick, Olds, Ford and Mercury) or sheet metal changeover (e.g., full-sized Chevrolet). But since the 1969-73 period was a time of stability in car design -- well before the era of downsizing but long after the diversification of the early 1960's -- body changeovers did not lead to the production of a truly different car.

4.4.4 Some current research concepts in side impact protection

The scope of this evaluation is limited to the modifications, in response to Standard 214, in actual production vehicles of the 1969-78 era, especially the first half of that period. The following discussion of current (1979-82) research concepts in side impact protection is not, in any sense, an evaluation of the merits of various concepts. It is an attempt to relate some of the ideas in current research to the ideas and hypotheses that were formulated in the development of Standard 214 (Section 4.3). It is a bridge between the results of this evaluation, which are based on the highway accident experience of production vehicles, and the current literature on side impact research.

Much research has been devoted to an upgrading of the structural strength of the side of a car. (For example, see [41].) In most cases, the prototype upgraded cars continue to have door beams. But the upgrade extends to many structures other than the beam (pillars, roof rails, roll bars). Also, the beam itself is upgraded and plays an important role in the improved side structure. Improvements to beams include increasing its vertical size to partially close the gap between the beam and the sill, installing tabs from the beam to the sill, and greatly strengthening the areas where beams transmit forces to hinges, latches and pillars in crashes. The rationale for these developments are: (1) It is desirable to retain the beam because it has the property of deflecting striking objects (see the discussion under Hypothesis 2 in Section 4.3.1). (2) The energy absorbing capacity of the beam is limited. Most energy is absorbed by other structures -- so they need to be upgraded. The beam is best used to transmit loads to other structures (see the discussion under Hypothesis 1). (3) Every effort must be devoted to preventing sill override; for this reason the beam is lowered and tabs to the sill are added (see under Hypothesis 3).

Other research emphasizes the problem of sill override, using crash tests to demonstrate that a raising of sills <u>or</u> lowering of bumpers (on the striking vehicle) produces the same reduction of penetration, at far lower incremental weight, as a massive side structure upgrade [48], [68]. This research is, in a sense, a continuation of Hedeen and

Campbell's tests with high sills (see Section 4.2.1) and a follow-up on letters to the Standard 214 docket recommending that the compliance test be performed with the impactor at a fixed height from the ground, thereby encouraging high sills (4.2.2).

Another approach is to soften the first 20 inches or so of the frontal structure of the striking vehicle, as a means to redress the strength imbalance between side and frontal structures (see the discussion under Hypothesis 1) [48]. The rationale is that the incremental cost and weight of bringing side strength up to a par with frontal strength is much greater than that of lowering frontal strength. Also, a soft front end could be beneficial in reducing aggressiveness in pedestrian impacts while only minimally reducing crashworthiness in frontal impacts (since there is still a large amount of crushable material behind the first 20 inches).

Interior padding has been given attention, both as a complement and partial substitute for structural upgrading [74]. The rationale for improving padding is: (1) Many serious injuries in side impact are not necessarily attributable to contact with intruding side surfaces (see Section 3.2.2). (2) Massive structural upgrade may have prohibitive cost and incremental weight. (3) After structural upgrade, there may be little intrusion in severe crashes, but even without intrusion, occupant contacts with unpadded side surfaces may cause serious injuries in those crashes.

In recognition of the large number of serious head injuries in side impacts (see Section 3.2.1), consideration has been given to designing side windows with the injury-mitigating properties of the High Penetration

Resistant windshield [76]. This approach has been difficult to reconcile with automobile owners' wishes for windows that can be opened.

Finally, it has been attempted to make the vehicle's seats a major load bearing structure that supports the door in crashes, possibly dispensing with beams [26]. It is unknown whether a vehicle without beams would be effective in deflecting a striking object (see Hypothesis 2 in Section 4.3.1).

CHAPTER 5

REVIEW OF PREVIOUS STATISTICAL STUDIES OF STANDARD 214

Seven published effectiveness studies of Standard 214, based on statistical analyses of accident data, are reviewed in this chapter. Three of the studies are based on investigator-collected accident data, 2 on police reports, one on investigator and police-collected data and one on insurance claims.

The studies are based on subsamples of the data analyzed in Chapters 7 and 8 of this report or on comparable but much smaller data sets. As a consequence, the studies are essentially superseded by Chapters 7 and 8 of this report and shed little additional light on the effectiveness of Standard 214.

5.1 Preston & Shortridge (1973) - Denver, MDAI and Texas data

Three data files residing at the University of Michigan computer facility were analyzed: Denver accidents in 1972, the Multidisciplinary Accident Investigation file, and a 5 percent sample of Texas accidents in 1972 [67].

In Denver, injured drivers and right front occupants in "broadside" and "sideswipe" side impacts were selected. The cases were tabulated by Standard 214 compliance, injury severity and seating position (see Table 6 of [67]). The authors claimed that there was no significant difference in the injury distribution of pre and post-standard car occupants. But it appears that their statistical test had unnecessary degrees of freedom (i.e., it kept K,A,B and C as separate categories). If their data in Table 6 are collapsed as follows:

	Pre-Standard 214	Post-Standard 214
Nonminor injury (K,A,B)	265	55
Minor injury (C)	145	52

then there is a statistically significant reduction of nonminor injury in the post-standard cars (chi-square=6.30, $p < .05$). Of course, this significant reduction need not be due to Standard 214 alone. Their data set covers a wide range of model years. Since police-reported injury rates (especially nonminor injury rates) increase swiftly as cars get older the reduction may, to a large extent, be due to the fact that the pre-standard cars are substantially older than the post-standard cars.

On the Multidisciplinary Accident Investigation file, Preston and Shortridge identified 116 occupants of 1969-73 cars that had been sitting adjacent to a struck door; the sample was divided about equally between pre and post-standard car occupants. They performed a regression of the occupant's AIS (injury severity rating [1]) by Standard 214 compliance, seat position and belt usage. Standard 214 was found to reduce AIS by an average of .48. This was not a significant reduction (p=.16), which is hardly surprising considering how small the sample was.

They also compared the average depth of crush in the MDAI side impacts and found no significant difference between the 65 pre-standard and 89 post-standard cars on the file - sample sizes that are less than 5 percent as large as those available for Chapter 9 of this report.

They did not find any significant injury reduction for Standard 214 in a 5 percent sample of Texas accidents in 1972. Note that Chapter 8 is based on 100 percent samples of Texas accidents in 1972, 74 and 77.

5.2 Joksch (1973) - Texas data

Joksch analyzed the complete Texas accident files for 1971 and 1972 [42]. He divided cars into 4 cohorts, depending on the first year of beam installation. In each cohort, the ratio of nearside occupant injuries to farside occupant injuries is tabulated by model year. If side door beams are effective in reducing nearside injuries (with little or no effect on farside injuries), this ratio should drop significantly in the model year where beams were first installed. No such drops were found.

But Joksch's table of initial model years of beam installation (p. 55 of [42]) disagrees with Table 4-1 of this report on 36 of 68 models. If the model years indicated on Table 4-1 are correct, Joksch's results, which depend heavily on identifying the initial year of beam installation, are not meaningful.

5.3 McLean (1974) - North Carolina data

A.J. McLean selected cars struck in the door area in North Carolina police-reported accidents in 1971-72 [55]. Identification of the struck area was based on the TAD classification [82] -- codes LP and RP being used to indicate damage confined to the left or right passenger compartment, respectively. In North Carolina, during those years, the State Police were almost the only agency that filled in the TAD, so

McLean's study is essentially confined to State Police-reported (mostly rural) accidents.

Cars were assigned to pre or post-standard groups according to whether beams were installed. McLean's table of initial model years of beam installation (p. 66 of [55]) agrees completely with Table 4-1 of this report. Furthermore, in order to avoid biases in the injury rates due to excessively old cars, the pre-standard group was limited to model year 1965 or 66 and later.

Nearside occupants had significantly lower injury rates in beam-equipped cars than in cars without beams in <u>multivehicle</u> crashes. For example, there were 1391 drivers of standard-sized cars without beams that had LP damage; 16.4 percent were injured and 7.1 percent had K or A injury. The 846 drivers of comparable cars with beams had injury rates of 12.1 percent (overall) and 4.4 percent (K or A). These are statistically significant reductions of 26 percent in the overall injury risk (chi-square=7.85, $p<.05$) and 38 percent in the K+A injury risk (chi-square=6.94, $p<.05$). On the other hand, the observed reductions need not be due to Standard 214 alone. The beam-equipped cars are, on the average, 3-4 years newer then the cars without beams. Since police-reported injury rates increase substantially as cars get older, a good part of the observed reductions may be due to the vehicle age differences.

The sample of <u>single vehicle</u> crashes was much too small (74 pre-standard and 26 post-standard cases) for a meaningful statistical analysis.

5.4 Jones (1977) - Calspan data

Jones analyzed injury rates in cars that had been struck in the side by another car in the Calspan Level 2 data file [43]. The data, which were collected during 1967-75, resemble the National Crash Severity Study in that they contain, in many cases, the occupants' AIS injury severity and the vehicles' Collision Deformation Classification (CDC). The study was limited to cars in which the damage at least partially overlapped the occupant compartment (2nd letter of CDC was P, D, Y or Z). A major advantage of Calspan Level 2 data is that the sample is limited to cars less than 18 months old at the time of the accident - thus eliminating vehicle age difference of pre and post-standard cars on the file.

The file contained 2007 occupants of pre-Standard 214 cars and 2417 post-standard car occupants involved in side impacts, as described above. The occupants of post-standard cars had a 28 percent lower AIS$\geq$3 injury rate, an 11 percent lower AIS$\geq$2 injury rate and a 4 percent lower rate of injuries resulting in transport to a hospital or emergency room; none of these reductions were statistically significant.

When the analysis is further restricted to nearside occupants, the injury reductions for the Standard 214 cars are 30 percent (AIS$\geq$3),11 percent (AIS$\geq$2) and 4 percent (transport to a treatment facility). Again, none of the reductions are significant.

The Calspan Level 2 data contain about 1/6 as many serious injuries as the NCSS data analyzed in Chapter 7 of this report. Because the Calspan sample is so much smaller than NCSS, none of the observed injury reductions is statistically significant; nevertheless the observed reductions are not inconsistent with the findings of this report.

5.5 Kahane (1979) - NCSS data

NHTSA's preliminary evaluation of Standard 214, published in 1979, was based on analysis of the 5557 National Crash Severity Study cases that were on file at that time [46]. Since then, the NCSS file has been completed and has grown to 12,050 accident cases. This reevaluation is based on the complete file and all NCSS results, especially those in Chapter 7, supersede those of the preliminary evaluation.

The main findings of the prelimary evaluation were the following injury rate reductions, for post-Standard 214 cars relative to pre-Standard cars (reductions stated in percent):

	In Single-Vehicle Crashes	In Multivehicle Crashes	Single and Multi, Combined
AIS $\geqslant 3$ reduction	66	-20	17
AIS $\geqslant 2$ reduction	60	- 4	18

Both injury reductions in single vehicle crashes were statistically significant; the injury increases in multivehicle crashes and the combined reductions were not significantly different from zero. The analyses were based on unrestrained nearside occupants of cars whose damage overlapped with the compartment (2nd letter of Collision Deformation Classification P, D, Y or Z). Vehicle weight and Delta V were used as control variables.

The principal conclusion of the preliminary evaluation was that Standard 214 reduces casualties in single-vehicle crashes. It made no conclusion regarding effectiveness in multivehicle crashes but stated that, even if subsequent analyses should indicate that Standard 214 reduces casulaties, the effectiveness would be lower than in single vehicle crashes.

Based on fatality counts in NCSS alone (i.e., without consideration of Fatal Accident Reporting System data), the preliminary evaluation estimated that Standard 214 might be saving as many as 3000 lives a year in single vehicle side impacts.

Some of the primary differences between the preliminary evaluation and this report - besides the large increase in the NCSS sample size - are:

o The current report uses FARS for an independent estimate of fatality reduction. The results are much more reliable than those of the preliminary report, which are based on NCSS.

o The preliminary report used AIS-based injury criteria, which lead to large sampling errors when used with NCSS data. Moreover, the adjustment factor used for calculating sampling errors in the preliminary report probably understates those errors. The current report uses hospitalization as the injury criterion, which is ideally suited for NCSS, and obtains realistic estimates of sampling error by a direct, empirical technique.

o The category of side impacts considered in the preliminary evaluation (nearside occupants with 2nd letter of the CDC being P, D, Y or Z) has been superseded for the reasons shown in Chapters 9 and 10 of this report. It is a more refined approach to analyze, initially, all occupants in all side impacts - broadening the sample and reducing sampling error. Then, for multivehicle crashes, the reevaluation considers an even narrower category of damage than the one used in the preliminary report, isolating those crashes where Standard 214 is really effective.

o This report considers a wide range of control variables, including the major side structural modifications other than Standard 214.

o This report presents analyses restricted to a limited number of model years before or after the installation of beams, limiting vehicle age-related biases.

Despite the preceding shortcomings, the preliminary evaluation generated some important information. The decision to analyze single-vehicle and multivehicle crashes separately has been vindicated by Chapters 9 and 10 of this report, which indicate that Standard 214 works by quite different mechanisms in the two crash types. Moreover, the preliminary conclusion that Standard 214 is more effective in single-vehicle than in multivehicle crashes is confirmed by Chapters 6 and 7 of this report (although the observed difference in effectiveness is smaller now than before). Finally, the overall effectiveness in the preliminary evaluation (single and multivehicle crashes, combined) is close to the overall effectiveness in this report.

5.6 Cameron (1980) - Victoria insurance claims

Australian Design Rule 29 is almost indentical to Standard 214. It took effect in 1977 and side door beams were installed in cars sold in Australia beginning with the 1977 model year. Cameron analyzed no-fault injury compensation claims in the State of Victoria for 1977-78 [7]. He compared the injuries of nearside front seat occupants post-standard (1977-78) cars that were struck in the side to injuries in pre-standard (1971-76) cars. The analytic technique was to compare the ratio of nonminor to minor injuries. The sample contained only 110 injuries in post-standard cars, about half of which (53) were nonminor. Similarly, half of the injuries in the pre-standard cars were nonminor, so no reduction of injury severity was observed in the sample. Moreover, when the nonminor injuries were subdivided into 11 descriptive groups (by body region and lesion), no statistically significant reduction was observed in any of the groups, for post-standard cars, relative to minor injuries. (Lack of significance is hardly surprising when 53 injuries are divided into 11 groups.) The report is subtitled, "A Preliminary Study," so it may be presumed that a follow-up will be performed when more data are available.

5.7 Chi (1980) - NCSS data

A second NCSS analysis was performed by the Highway Safety Research Center, a NHTSA contractor, in 1980 when the file contained 10,851 accident cases (90% complete) [11]. Chi's findings superseded the preliminary NHTSA evaluation (see Section 5.5), which was based on 5557 NCSS cases and a less detailed analysis. In turn, Chi's report is superseded by the present NHTSA reevaluation, which is based on the complete NCSS file and incorporates further analytical improvements.

Chi's analysis was limited to nearside front-seat occupants of cars whose damage at least partially overlapped the compartment (2nd letter of CDC was P, D, Y or Z). Single and multivehicle crashes were, as a rule, not separately analyzed; however, "number of vehicles in the accident" was included among the potential control variables.

Standard 214 reduced the likelihood of AIS$\geqslant$3 injuries by a statistically significant 21 percent (confidence bounds: 4 to 38). It reduced AIS$\geqslant$2 injuries by a nonsignificant 12 percent (confidence bounds: -5 to 29). In the AIS$\geqslant$2 analysis, "number of vehicles in the accident" was selected as a control variable. As a result, separate effectiveness estimates were obtained for single vehicle crashes (25% reduction of AIS$\geqslant$2) and multivehicle crashes (8% reduction). Separate estimates were not obtained for AIS$\geqslant$3.

The effectiveness estimates are based on a detailed multivariate analysis, with sequential selection of control variables. The list of potential control variables included side structure characteristics other than Standard 214: type of B pillar, number of doors, bench or bucket seat. (It did not include body-and-frame vs. unitized construction, which turned out to be key control variable in Chapter 7 of this report.)

An analysis of door instrusion was carried out using the intrusion data elements coded on NCSS beginning in April 1978. Because of the high rate of missing data on those variables, the analysis was limited to 219 cases. It attributed a statistically significant 2 inch reduction of door intrusion to Standard 214.

Some of the primary difference between Chi's methods of analyzing NCSS and the present report are:

o Chi did not perform separate analyses of single and multivehicle crashes. This report does and, moreover, Chapter 6, 7, 9 and 10 present strong evidence that it is desirable to perform separate analyses (partly because Standard 214 works by different mechanisms, partly because the control variables have quite different effects).

o Chi used AIS-based injury criteria, which lead to large sampling errors when used with NCSS data. Moreover, the adjustment factor used for calculating sampling error was basically the same as in Kahane's 1979 report and probably understates the width of the confidence bounds, especially when used with Chi's multivariate models. The present report uses a hospitalization criterion (more suitable for NCSS) and a direct, empirical procedure for analyzing sampling error.

o The category of side impacts used by Chi (nearside occupants with 2nd letter of the CDC being P,D,Y, or Z) is superseded by the categories used in this report (see Section 5.5 - same comment on Kahane's preliminary evaluation).

o Some of the control variables considered by Chi - including principal direction of force, extent of damage, horizontal damage location, vertical location, lateral Delta V - are shown in Section 7.4.4. and Chapter 9 of this report to be inappropriate as controls, because their measurement appears to be confounded by Standard 214.

o Chi relied on control variables as a means of removing biases in the effectiveness estimates due to differences of pre and post-Standard 214 cars, their drivers, etc. This report devotes considerable attention to biases that cannot be compensated by control variables. Above all, it includes effectiveness estimates based on a limited range of model yars before and after beam installation.

Despite the differences of analysis techniques, Chi's estimates of AIS$\geqslant$2 reduction come remarkably close to the estimates of hospitalization reduction made in Section 7.8 of this report.

CHAPTER 6

FATALITY REDUCTION FOR STANDARD 214: ANALYSES OF FARS DATA

The Fatal Accident Reporting System (FARS) contains a virtual census of the fatalities that have occurred since January 1, 1975. As of April 1982, FARS contained over 175,000 passenger car occupant fatalities, which have occurred over a 7-year period (1975-81). FARS is a powerful tool for estimating the fatality reduction due to a safety standard: an estimate of fatality reduction that is independent of the injury reduction estimates from other data files. FARS was used in earlier evaluations to investigate the effect of energy-absorbing steering columns ([44], pp. 197-211) and head restraints ([45], pp. 161-177). The analysis methods developed in those studies are also applicable to Standard 214.

There is definitive evidence that Standard 214 has significantly reduced the fatality risk in single vehicle side impact crashes. The reduction is about 14 percent, which corresponds to an annual prevention of 480 fatalities. On the other hand, Standard 214 has little or no effect on the risk of death in multivehicle side impact crashes - as will be shown in this chapter.

6.1 Analysis methods

There are some difficulties in using FARS data. Since FARS only contains fatal accidents, it is not possible to compute fatality rates per 100 (fatal or nonfatal) crash involved occupants. So it is not possible to directly compare the occupant fatality rates of pre- and post-Standard 214 cars. FARS can, however, be used to compute indirectly the relative fatality risk of pre- and post-Standard 214 cars: The occupant fatalities in side impacts are compared to a control group of fatalities unaffected by Standard 214. The side impacts and the control group should be similar except for the possible effect of Standard 214. The fatalities are then tabulated by pre/post, for the control group and the side impacts:

FATALITIES	control group	side impacts
last model year without side door beams	N_{11}	N_{12}
first model year with side door beams	N_{21}	N_{22}

The ratio N_{21}/N_{11} is an indirect measure of the likelihood of post-standard car fatalities relative to pre-standard. It takes into account the differences of exposure and the effects of other safety devices (if any). If Standard 214 had no effect in side impacts, the expected number of fatalities in post-standard side impacts would be $N_{12} (N_{21}/N_{11})$. Thus

$$\varepsilon = 1 - \frac{N_{22}\ N_{11}}{N_{12}\ N_{21}}$$

is a measure of the effectiveness of Standard 214 in side impacts. This analysis method was used in the evaluations of energy-absorbing steering systems and head restraints.

For the analysis to be valid, it is essential to minimize or eliminate potential sources of bias, such as changes in the vehicle fleet other than the implementation of Standard 214 or effects related to differences in vehicle age. This is accomplished by:

(1) restricting the age range of the cars under study as much as possible - preferably studying only cars of the last year without and the first year with side door beams.

(2) eliminating from the study those makes and models that were built only before or only after Standard 214 implementation - thereby assuring that the pre- and post-standard groups comprise basically the same set of makes and models.

Frontal impacts are chosen as the control group. They make a good control group because, during the implementation period of Standard 214 (1969-73), no major safety devices that affect frontal impacts were installed (see Section 4.4).

Separate analyses are performed for single vehicle and multivehicle crashes. (Single-vehicle frontal impacts are the control group for single-vehicle side impacts; multivehicle frontals for multivehicle side.) FARS does not specify whether damage occurred in the passenger compartment area, so compartment-damage crashes could not be isolated from the others. FARS does, however, indicate which side of the car was struck and on which side the occupant sat. Thus, analyses are performed separately for nearside and farside occupants and for both groups combined.

These analyses and their resuslts are described in Section 6.3, "Analyses of side/frontal contingency tables."

A possible shortcoming of these analyses is that the ratio of side to frontal impacts may vary with vehicle age - e.g., older cars may have relatively more head-on and fewer angle collisions. (See Appendix F of [45], which attributes this tendency to the fact that older cars are, on the average, driven more aggressively and are somewhat overrepresented in nonmetropolitan areas.) If so, the difference in the ratios found in the preceding analyses may in part be due to vehicle age biases. It is useful to check the ratio of side to frontal fatalities over a range of vehicle ages and find out if there is a trend. The effectiveness of Standard 214 is measured by the amount of deviation from the trend line in the year that side door beams were introduced. Section 6.4, "regressions of the proportions of side and frontal fatalities," uses this approach.

Even though frontal fatalities would appear to be a good control group for the period of Standard 214 implementation, there remains the possibility that the effect attributed to Standard 214 in the preceding analyses could be due to some unanticipated change in the control group. It is desirable, then, to perform some kind of analysis without a control group. With vehicle registration data and FARS side impact fatality counts, it is possible to calculate the side impact fatality rate <u>per 1000 registered vehicle years</u>, for a given class of vehicles in a given calendar year. As a result, it is possible to calculate the average side fatality rate, per 1000 vehicle years, during 1975-81, for cars built one year before beams were installed and for cars of the first year in which beams were installed. The difference in the two rates gives yet another estimate for the effectiveness of Standard 214 - see Section 6.5, "side impact fatalities per 1000 vehicles years."

A probable shortcoming of this analysis is that the side impact fatality risk per 1000 vehicle years is quite likely to increase as vehicle age increases. In Section 6.6, "regression of side impact fatality rates per 1000 vehicle years," the trend of the fatality rates and the deviation from the trend attributable to Standard 214 are analyzed.

6.2 Data preparation

Fatalities from the 1975-81 FARS files were selected and prepared for analysis as follows:

(1) Only passenger cars from model years 1967-75 were selected. That time period covers from two years before the earliest cars with side door beams through two years after the last cars received the beams. It was a rather homogeneous group of cars: all pre-downsizing and (except for some of the 1967's) meeting the major frontal crashworthiness standards.

(2) Side and frontal impacts were defined according to the "principal impact point." Left-side impacts were those with 8-10 o'clock impact points; right-side, 2-4 o'clock; frontal, 11, 12 or 1 o'clock.

(3) Drivers and left-rear passengers were classified as "nearside" occupants in left-side impacts, "farside" in right-side impacts; vice-versa for right-front and right-rear passengers. Passengers in other and unknown seating positions were not used (both in frontal and side impacts).

(4) The definitions of "single vehicle" and "multivehicle" crashes varied from year to year on FARS. For 1979-81, the vehicle's

"most harmful event" was used: "single vehicle crashes" were those which did not involve a collision with a motor vehicle (codes 12-14). For 1976-78, this data element was not coded; "number of vehicles," an accident-level variable, was used. In 1975, this variable was also uncoded, so the accident-level variable "first harmful event" was used in the same way as "most harmful event" was used in 1979-81. The objective here was to classify as multivehicle those crashes in which the catastrophic contact involved another motor vehicle. The criteria for 1975-78 resulted in a small number of misclassifications.

(5) Major objectives were to obtain "comparable" samples of pre- and post-standard cars and to pinpoint the last model year without beams and the first model year with them. As a result, the following makes and models were deleted from the study:

o all imported cars except the Volkswagen Beetle, since it is uncertain exactly when they began to contain beams (see Table 4-1).

o 1970 Camaros and Firebirds; 1973 Beetles and Chrysler Corporation cars (except Challengers and Barracudas): beams may have been installed in midyear.

o Chevrolet Corvairs, which never had beams, nor is there a comparable model which had them.

o Chevrolet Vegas, Ford Granadas, Cadillac Sevilles, etc., which always had beams, but there is no comparable model which did not.

These makes and models produced only with (without) beams for which there were more or less comparable models without (with) beams were, however, not deleted. For example, the 1975 Olds Omega was retained because the 1972 and earlier Chevrolet Nova were comparable cars without beams. Similarly, if a car line merely changed its name, it was not excluded (e.g., Buick Wildcat and Centurion). Finally, the intermediate based Chevrolet Monte Carlo and Pontiac Grand Prix were retained even though they always had beams: it was felt that the sporty 2 door hardtop versions of the Chevelle, GTO, and LeMans were more or less comparable pre-Standard 214 cars. Similarly, Dodge Challengers are more or less comparable to the 1970 and earlier Chargers.

(6) The year of Standard 214 implementation was pinpointed in each make and model, based on Table 4-1. Models not listed in that table are classed with similar body types that are listed (e.g., Mercury Bobcat with Ford Pinto). For Camaro and Firebird, the year is 1970.5; for Chryslers and VW Beetles, it is 1973.5. Next, the number of years before or after the implementation year is pinpointed for each model/model year combination - e.g., the 1972 Nova is the last year without beams, the 1973 Nova is the first year with them. For Camero and Firebird, the "last year without" is 1969; the "first year with" is 1971. Chrysler and VW are similarly handled.

Dodge Chargers require special attention since they are really two different cars: up till 1970, they are specialty cars comparable to the Challenger; starting 1971, they are intermediates comparable to the Coronet. The problem is complicated because FARS make/model codes changed in 1980 and 1981. Refer to Appendix A for details on classifying the Chargers, as well as other details on the data preparation.

6.3 Analysis of side/frontal contingency tables

6.3.1 First year with beams vs. last year without them

With the definitions of the preceding section, it is possible to select and tabulate all the nearside, farside, and frontal fatalities that occurred (during 1975-81) in cars of the first full model year in which beams were installed - e.g., 1969 Impalas, 1970 Cutlasses, 1971 Camaros and Mustangs, 1972 Thunderbirds, 1973 Gremlins and 1974 Valiants. Similarly, it is possible to select and tabulate fatalities in comparable models of the last full model year before beams were installed - e.g., 1968 Impalas, 1969 Cutlasses and Camaros, 1970 Mustangs, 1971 Thunderbirds, and 1972 Gremlins and Valiants. These model/year combinations form the basis for the contingency table analysis.

Table 6-1 shows the fatality counts in single vehicle accidents. Frontal fatalities remained nearly unchanged (2349 in the last year before beams, 2371 in the first year with beams). Nearside fatalities, however, decreased from 776 to 659. The decrease in the nearside fatalities, relative to the frontals was:

$$1 - (659/776)/(2371/2349) = 16 \text{ percent}$$

and it was statistically significant (chi-square = 8.18, $p < .05$). There was a comparable decrease of 10 percent in the farside fatalities although it was not quite statistically significant (chi-square = 2.27). The fatality reduction in all types of single vehicle side impacts - nearside and farside combined - is 13 percent and it is statistically significant (chi-square = 8.33).

This FARS analysis confirms engineering intuition (Section 4.3.1) and crash damage data (Chapter 9) that Standard 214 is effective in reducing fatalities in single vehicle side impacts. Moreover, the results are consistent with the hypotheses that the standard is beneficial for nearside and farside occupants - although this is not, so far, a firm conclusion because the observed reduction for farside occupants (10%) was not quite significant. In the next section, one more model year of cars will be added to each side of the sample (i.e., last 2 years before vs. first 2 years after Standard 214) to check whether the fatality reduction in single vehicle crashes persists in the larger sample.

Table 6-2 shows the fatality counts in multivehicle accidents. Frontal fatalities remained nearly unchanged (2991 in the year before vs.

TABLE 6-1

SIDE AND FRONTAL FATALITIES IN SINGLE-VEHICLE CRASHES,
FIRST YEAR WITH BEAMS VS. LAST YEAR WITHOUT THEM, FARS 1975-81

	Frontal	Nearside	Frontal	Farside	Frontal	Near and Farside
Last model year without beams	2349	776	2349	548	2349	1324
First model year with beams	2371	659	2371	499	2371	1158
Side impact fatality reduction	16%		10%		13%	
Chi-square	8.18 (signif., α = .05)		2.27 (not signif.)		8.33 (signif.)	

TABLE 6-2

SIDE AND FRONTAL FATALITIES IN MULTIVEHICLE CRASHES,
FIRST YEAR WITH BEAMS VS. LAST YEAR WITHOUT THEM, FARS 1975-81

	Frontal	Nearside	Frontal	Farside	Frontal	Near and Farside
Last model year without beams	2291	1325	2991	641	2991	1966
First model year with beams	2995	1420	2995	662	2995	2082
Side impact fatality reduction	-7%		-3%		-6%	
Chi-square	2.16 (not signif.)		0.26 (not signif.)		1.89 (not signif.)	

2995 in the year after beams were installed) but nearside fatalities increased from 1325 to 1420 in the cars with beams. This is a 7 percent increase in nearside fatalities, which is, however, not statistically significant (chi-square = 2.16). Farside fatalities also increased slightly - by 3 percent. The overall fatality increase in multivehicle crashes (nearside and farside combined) is a nonsignificant 6 percent.

The FARS results are, at least, consistent with the hypotheses (Sections 4.3.1, 9.3.3 and 10.2.3) that Standard 214 would not have large fatality-reducing benefits, even for nearside occupants, in multivehicle crashes and that it would have little or no effect on the farside occupants. On the other hand, the observed increase in nearside fatalities, although not statistically significant, is a matter for concern and suggests a need for the analyses that follow. As a first step, the sample is broadened to include one more model year on each side.

6.3.2 First two years with beams vs. last two years without them

Table 6-3 compares the fatality counts in single-vehicle accidents for cars of the last two model years without beams vs. the first two model years with them. Frontal fatalities remained virtually unchanged (4325 without beams, 4303 with them). But side impact fatalities (near and farside combined) dropped from 2505 to 2137. This is a relative decrease of 14 percent and it is statistically significant (chi-square = 17.78). The decrease is nearly identical to that which was shown in the preceding section (13%). Moreover, with the additional model year of data on each side, the reduction in farside fatalities has become statistically significant and, as a matter of fact, it is virtually the same as the nearside fatality reduction (15% vs. 14%). Thus, the addition of an extra model year on each side hardly changed the results - it only strengthened their statistical significance. The ratio of side to frontal fatalities, in other words, changed significantly in the year that beams were introduced but hardly changed at all in the preceding and the subsequent year.

From this analysis, it is already clear that:

- Standard 214 significantly reduced the fatality risk in single vehicle side impact crashes

- The reduction was virtually the same for nearside and farside occupants

Nevertheless, alternative estimates of the single-vehicle fatality reduction will be obtained in the remainder of this chapter, in order to check that the effects observed here are indeed due to Standard 214 and not some anomaly in the control group. However, only the remaining analyses for near and farside occupants combined will be performed, since it is evident that Standard 214, if indeed effective, is effective for both types of occupants.

Table 6-4 compares the fatality counts in multivehicle crashes. Again, the addition of a model year on either side left the results virtually unchanged. Frontal fatalities were nearly the same (5652 in the 2 years before vs. 5627 in the 2 years after). Nearside fatalities increased from 2541 to 2728, which is an increase of 8 percent relative to the frontals. The increase is just a bit more than what was found in the preceding section (7%). Moreover, since the sample is nearly twice as large, the increase has become statistically significant (chi-square = 5.11). Could this mean that Standard 214 actually increases multivehicle crash fatalities or is there a bias in the analysis technique (viz., that newer cars have a higher ratio of angle to head-on collisions than older cars)? The question is addressed by the remainder of this Chapter.

Table 6-4 does confirm, however, that Standard 214 has little or no effect on the fatality risk of farside occupants in multivehicle crashes. The observed increase of 3 percent is identical to what was found in Table 6-2 and is nonsignificant (chi-square = 0.51) despite the large number of fatalities in the sample. The farside fatalities are omitted from the multivehicle crash analyses in the remainder of this chapter, since it appears that the engineering and statistical evidence is already sufficient to conclude that Standard 214 has negligible effect on them.

TABLE 6-3

SIDE AND FRONTAL FATALITIES IN SINGLE-VEHICLE CRASHES,
FIRST TWO YEARS WITH BEAMS VS. LAST TWO YEARS WITHOUT THEM, FARS 1975-81

	Frontal	Nearside	Frontal	Farside	Frontal	Near and Farside
Last two years without beams	4325	1451	4325	1054	4325	2505
First 2 model years with beams	4303	1247	4303	890	4303	2137
Side impact fatality reduction	14%		15%		14%	
Chi-square	10.98 (signif., α = .05)		10.62 (signif.)		17.78 (signif.)	

TABLE 6-4

SIDE AND FRONTAL FATALITIES IN MULTIVEHICLE CRASHES,
FIRST TWO YEARS WITH BEAMS VS. LAST TWO YEARS WITHOUT THEM, FARS 1975-81

	Frontal	Nearside	Frontal	Farside	Frontal	Near and Farside
Last two model years without beams	5652	2541	5652	1182	5652	3723
First 2 model years with beams	5627	2728	5627	1215	5627	3943
Side impact fatality reduction	-8%		-3%		-6%	
Chi-square	5.11 (signif.)		0.51 (not signif.)		4.36 (signif.)	

6.3.3 Confidence bounds for the fatality reduction in single vehicle crashes

The estimate of fatality reduction in single vehicle side impacts that was obtained in Section 6.3.2 was based on combining 7 calendar years of FARS data (1975-81). Each of the individual calendar years of FARS is a subsample of the file that was used.

An empirical and conservative method for estimating the error of the FARS result is to perform the calculation of effectiveness separately for each of the 7 calendar years of FARS and to examine the variation of the results. This approach was used in the evaluation of energy-absorbing steering columns ([44], pp. 204-209) and head restraints ([45], pp. 165-168).

Table 6-5 compares the side and frontal fatalities in single vehicle crashes, last two years before vs. first two years after Standard 214, by calendar year of FARS. "Side" fatalities include near and farside occupants. Table 6-5 is identical to the rightmost portion of Table 6-3, except that the data have been subdivided by calendar year of FARS. The effectiveness of Standard 214 is also calculated for each calendar year. It is always greater than zero, ranging from a 3 percent fatality reduction in 1978 to a 20 percent reduction in 1976 and 1980.

TABLE 6-5

SIDE AND FRONTAL FATALITIES IN SINGLE-VEHICLE CRASHES, FIRST TWO YEARS WITH BEAMS VS. LAST TWO YEARS WITHOUT THEM, FARS 1975-81, BY CALENDAR YEAR

FARS Calendar Year	Car Model Years	Single-Vehicle Crash Fatalities Frontal	Side	Total N_i	Observed Effectiveness of Std. 214 (%) E_i
1975	Last 2 MY w/o beams	688	440	2027	8.44
	First 2 MY w. beams	567	332		
1976	Last 2 MY w/o beams	729	466	2206	20.38
	First 2 MY w. beams	670	341		
1977	Last 2 MY w/o beams	718	379	2024	8.46
	First 2 MY w. beams	625	302		
1978	Last 2 MY w/o beams	675	358	2011	2.64
	First 2 MY w. beams	647	331		
1979	Last 2 MY w/o beams	609	355	1909	18.64
	First 2 MY w. beams	641	304		
1980	Last 2 MY w/o beams	537	303	1841	20.49
	First 2 MY w. beams	691	310		
1981	Last 2 MY w/o beams	369	204	1252	15.04
	First 2 MY w. beams	462	217		
7 Year Total	Last 2 MY w/o beams	4325	2505	13,270	14.25
	First 2 MY w. beams	4303	2137		

Let E_i be the effectiveness estimate based on FARS data from calendar year i and N_i be the total number of fatalities in the table for year i (side plus frontal, pre plus post). Note that $\hat{E}$ = 14.25 percent is the overall effectiveness of Standard 214 for the 7 years of FARS combined. Let

$$S = \left(\frac{7 \sum_{i=1975}^{1981} N_i \left(E_i - 14.25 \right)^2}{6 \sum_{i=1975}^{1981} N_i} \right)^{1/2} = 9.85$$

Then S is a measure of the variation of the FARS effectiveness estimates from year to year. (A weighted sum of squares is used because the available sample size varies from year to year and $\hat{E}$ = 14.25 is used rather than the average of the E_i's because the latter is a biased estimate of effectiveness.)

Let E be the effectiveness of Standard 214 calculated using 7 years of FARS. Then $(E - \hat{E})/(S/\sqrt{7})$ is roughly t distributed with 6 degrees of freedom. Thus, a <u>lower confidence bound for effectiveness</u> (one-sided α = .05) is given by

$$\hat{E} - 1.943\ S/\sqrt{7} \quad = 7 \text{ percent}$$

The <u>upper confidence bound for effectiveness</u> is

$$\hat{E} + 1.943\ S/\sqrt{7} = 21 \text{ percent}$$

6.4 Regressions of the proportions of side and frontal fatalities

The preceding analyses of multivehicle crashes may have resulted in a bias against Standard 214: the post-standard cars were, on the average, 1 year newer than the pre-standard cars in Section 6.3.1 and 2 years newer in Section 6.3.2. Newer cars tend to have a higher ratio of (fatal and nonfatal) side impacts to frontal impacts than old cars - see, for example, Appendix F of [46]. Therefore, a somewhat higher ratio of side to frontal fatals would also be expected in the post-standard cars: a spurious "negative" effect for Standard 214. Of course, the effect was probably small, because the age difference in the preceding analyses was just 1 or at most 2 years. But it could have been the factor that produced the significant fatality increase found in Section 6.3.2.

Multiple regression analysis of the side and frontal fatality counts over the full range of model years 1967-75 permits removal of the vehicle age bias. In addition, the analysis helps check whether the results from Section 6.3, which were based on a narrow range of model years, are consistent with results based on a broader sample. For this purpose, the regression is also performed on the single-vehicle crash fatality counts.

When the full range of model years 1967-75 is analyzed, two further problems arise. First, beams were not introduced in all cars at the same time, but were generally introduced first on the larger cars, which have lower fatality rates. Unless this is accounted for in the analysis, the regression model may spuriously attribute to Standard 214 an "effect" which is actually due to the order in which beams were introduced. The other problem is that 1967 Ford Motor and Volkswagen cars do not have energy-absorbing steering columns - thereby reducing the ratio of side to frontal fatalities for a reason unrelated to Standard 214. These models (which were never used in Section 6.3, since they are more than 2 years before beams were installed) have to be excluded from the regressions.

The makes and models on FARS are grouped into 7 classes, according to the model year in which beams were first installed (see Section 6.2). The fatality counts (side and frontal impacts) are tabulated in each of these classes by model year (1967-75) and calendar year (1975-81). For single-vehicle crashes, the dependent variable is

$$R_1 = \frac{\text{side single-veh. fatalities}}{\text{side single-veh. fats} + \text{frontal single-veh. fats.}}$$

For multivehicle crashes, the dependent variable is

$$R_2 = \frac{\text{nearside multiveh. fatalities}}{\text{nearside multiveh. fats} + \text{frontal multiveh. fats.}}$$

for a given beam implementation year, model year and calendar year.

The independent variables are

BEAMS = 1 if beam-equipped; 0 if not beam equipped

AGE = vehicle age = calendar - model year

AGE^2, to account for possible nonlinearity of the age effect

T70, T70.5, T71, T72, T73, T73.5 - indicating the model year in which the transition to beams was made. For example, T71 = 1 for cars which first obtained beams in 1971, = 0 otherwise. Note that for full-sized GM cars (transition in 1969), all of these variables are zero.

CY75, CY76, CY77, CY78, CY79, CY81 - indicating calendar year. For example, CY77 = 1 for 1977 accidents, = 0 otherwise.

Over the 7 years of FARS data, AGE ranges from 3-14 for the pre-standard cars and from 0-12 for the post-standard cars. In other words, the ranges overlap greatly and AGE is not confounded with BEAMS in a manner that would invalidate the regression. The regression weight factor for single vehicle crashes is

N_1 = side single-veh. + frontal single-veh. fatalities

and for multivehicle crashes it is

N_2 = nearside multiveh. + frontal multiveh. fatalities

The regression equation that best fits the observed, weighted data on <u>single-vehicle</u> accidents is

$$
\begin{aligned}
R_1 = {} & .2704 - .0307 \text{ BEAMS} \\
& + .0088 \text{ AGE} - .0006 \text{ AGE}^2 \\
& + .0481 \text{ T70} + .0745 \text{ T70.5} + .0517 \text{ T71} + .0484 \text{ T72} \\
& + .0415 \text{ T73} + .0341 \text{ T73.5} \\
& + .0457 \text{ CY75} + .0432 \text{ CY76} + .0174 \text{ CY77} + .0149 \text{ CY78} \\
& + .0222 \text{ CY 79} + .0298 \text{ CY81}
\end{aligned}
$$

and the multiple correlation coefficient is .44 and df = 409. The negative coefficient for BEAMS suggests that Standard 214 is effective - i.e., it reduces side fatalities relative to frontal fatalities.

The weighted average of R_1 was

$$\bar{R}_1 = .3444$$

Since about half of the cars in the sample are equipped with side door beams, a good approximation of the observed <u>effectiveness of the beams in single-vehicle crashes</u> is given by

$$1 - \left(\frac{\bar{R}_1 - .0307/2}{\bar{R}_1 + .0307/2} \bigg/ \frac{1 - (\bar{R}_1 - .0307/2)}{1 - (\bar{R}_1 + .0307/2)} \right) = 13 \text{ percent}$$

where −.0307 is the regression coefficient for BEAMS.

This estimate is nearly identical to the estimates of the preceding section (which were 13 percent for last year before vs. first year after and 14 percent for last 2 years before vs. first two years after). Thus, the inclusion of a wider range of model years and control for vehicle age did nothing to change the previous results, which were apparently not biased.

The standard deviation of the regression coefficient for BEAMS is .01176. The null hypothesis that the coefficient is zero can be tested by computing $t = -.0307/.01176 = -2.61$. Since this quantity is in the critical region of a t distribution with 409 df, the null hypothesis is rejected. Standard 214 significantly reduces fatalities in single-vehicle crashes.

The regression equation that best fits the observed, weighted data on multivehicle accidents is

$$
\begin{aligned}
R_2 = {} & .3243 + .0092\ \mathrm{BEAMS} \\
& + .0005\ \mathrm{AGE} - .0003\ \mathrm{AGE}^2 \\
& .0253\ \mathrm{T70} - .0002\ \mathrm{T70.5} + .0326\ \mathrm{T71} - .0023\ \mathrm{T72} - .0047\ \mathrm{T73} \\
& - .0086\ \mathrm{T73.5} \\
& - .0216\ \mathrm{CY75} + .0033\ \mathrm{CY76} + .0041\ \mathrm{CY77} + .0079\ \mathrm{CY78} \\
& + .0077\ \mathrm{CY79} + .0019\ \mathrm{CY81}
\end{aligned}
$$

and the multiple correlation coefficient is .34 and df = 408. The positive coefficient for BEAMS suggests that the effectiveness of Standard 214 is negative - i.e., nearside fatalities increased relative to frontal fatalities.

The weighted average of R_2 was

$$\bar{R}_2 = .3232$$

Since about half of the cars in the sample are equipped with side door beams, a good approximation of the observed <u>effectiveness of beams for nearside occupants in multivehicle crashes</u> is given by

$$1 - \left(\frac{\bar{R}_2 + .0092/2}{\bar{R}_2 - .0092/2} \Big/ \frac{1 - (\bar{R}_2 + .0092/2)}{1 - (\bar{R}_2 - .0092/2)} \right) = -4 \text{ percent}$$

where +.0092 is the regression coefficient for BEAMS.

This estimate of the fatality increase is only about half as large as those of the preceding section (which showed a 7 percent increase for the first year after vs. the last year before and an 8 percent increase for the first 2 years after vs. the last 2 years before). Thus, the regression supports the conjecture that the earlier estimates may have contained a slight vehicle age bias which worked against Standard 214.

The standard deviation of the regression coefficient for BEAMS is .0106. The null hypothesis that the coefficient is zero can be tested by computing $t = .0092/.0106 = 0.87$. Since this quantity is well within the acceptance region of a t distribution with 408 df, the null hypothesis is acceptable in that Standard 214 has no effect on fatalities in multivehicle crashes.

6.5 Side impact fatalities per 1000 vehicle years

Each of the analyses so far used frontal impacts as a control group. It is possible that some of the effects attributed to Standard 214 could have been due to some unanticipated change in the frontal impacts such as:

- safety improvements other than Standard 214 in the year before, during or after Standard 214 implementation

- a coincidence that frontal fatalities, just by chance, happened to increase (or decrease) in the year that beams were installed

It would be desirable, then, to check the preceding results by developing a measure of side impact fatality risk which does not rely on the control group. The most suitable measure of risk - fatalities per 100 (fatal or nonfatal) accident-involved occupants - is unavailable because FARS does not provide counts of nonfatal accidents. Another measure of risk which has been used extensively by the Agency [8], is the number of fatalities per <u>1000 vehicle exposure years</u>. The fatality count from FARS for a particular group of makes and models in a particular calendar year is divided by the number of cars of that type that were on the road in that year. The latter number is derived from vehicle registration data.

Specifically, the objective is the fatality rate, during 1975-81, for cars of the first model year in which beams were installed (e.g., 1969 Impalas, 1970 Cutlasses, etc.). It is compared to the fatality rate, during 1975-81, for cars of the last model year in which beams were not installed (e.g., 1968 Impalas, 1969 Cutlasses, etc.). Fatality and registration counts are needed for calculating the rates. The fatality counts from FARS are shown in Tables 6-1 and 6-2. Registration counts could be readily computed if data were available for vehicle registrations by make and model, model year (1967-75) and calendar year (1975-81). In that case, it would be possible to pinpoint the specific model/year combinations that were the first year in which beams were installed and sum up the registrations, for those models and model years, over calendar years 1975-81. Unfortunately, registration data by make and model are not available for the range of model years and calendar years under consideration. A substitute for actual registration counts needs to be developed.

Production or U.S. sales of 1967-75 cars, by make, model and model year, are available from Ward's Almanacs for 1968-76. "MVMA Motor Vehicle Facts and Figures '81" provides, on p. 24, a table of the number of cars of a specific model year that are still on the road in the middle of any subsequent calendar year. That number can be divided into the original production to obtain the percentage of cars of a specific model year still on the road in a later calendar year - i.e., the percent of cars still on the road as a function of vehicle age. Table 6-6 gives the average percent of cars still on the road as a function of vehicle age. It is derived from the registration figures of 1965-75 cars in calendar years 1974-80 shown in the MVMA table. Finally, an estimate of the registrations by make, model, model year and calendar year is obtained by multiplying the original model year production by the percentage shown in Table 6-6 corresponding to the difference in model year and calendar year. For example, since 100,000 Cougars were produced in model year 1969, it is estimated that 55 percent of them - 55,000 - were still on the road in mid-calendar year 1979.

At this point, the model/year combinations which had beams for the first time were picked out (1969 Impalas, 1970 Cutlasses, etc.), excluding those which were not used in the FARS tabulations of fatalities (viz., 1971 Vegas - see Section 6.2), and the above estimates of exposure that each of these model/year combinations accumulated through 1975-81 were added up. A similar computation is performed for cars of the last model year without beams.

TABLE 6-6

PERCENT OF CARS STILL ON THE ROAD AS A FUNCTION OF VEHICLE AGE

Calendar Year Minus Model Year	Percent of Model Run Still Registered on July 1 of that Calendar Year
0	61*
1	100
2	99
3	98
4	95
5	92
6	89
7	83
8	75
9	65
10	55
11	44
12	35
13	28
14	22

*A substantial portion of the current model year run has not yet been sold and/or registered by July 1.

Table 6-7 shows the fatality rates per 1000 vehicle exposure years, during 1975-81, for cars of the first model year in which beams were installed and compares them to the rates for cars of the last year without beams.

TABLE 6-7

SIDE IMPACT FATALITY RATES PER 1000 VEHICLE YEARS,
DURING 1975-81, IN SINGLE-VEHICLE AND MULTIVEHICLE CRASHES,
FIRST YEAR WITH BEAMS VS. LAST YEAR WITHOUT THEM

	Vehicle Exposure Years in 1975-81	Single-Veh. Side Impact Fatalities, 1975-81		Multiveh. Nearside Fatalities, 1975-81	
	(000)	N	Rate	N	Rate
Last model year without beams	45,796	1324	.0280	1325	.0289
First model year with beams	51,699	1158	.0224	1420	.0275
Reduction for post-standard			23%		5%

Cars of the last model year before beams were installed accumulated a total of 45,796,000 vehicle years of exposure during 1975-81 and there were 1324 single vehicle side impact fatalities in those cars during those years. This is a rate of .0289 fatalities per 1000 years. Cars of the first model year with beams had 1158 single vehicle side impact fatalities in 51,699,000 exposure years during 1975-81 - a rate of only .0224 fatalities per 1000 years. Thus, the fatality rate in single-vehicle crashes decreased by 23 percent.

The fatality rate for nearside occupants in multivehicle crashes decreased by 5 percent in the year that beams were installed.

These findings are considerably more favorable to Standard 214 than any of the results using the frontal fatality control group. The single-vehicle crash fatality risk dropped by 23 percent here but by only 13 or 14 percent in the earlier analyses. The multivehicle crash fatality risk was <u>reduced</u> by 5 percent here, whereas in the earlier analyses it <u>increased</u> by 4 percent or more.

There is reason to believe, however, that the present findings contain a substantial vehicle age bias in favor of Standard 214. Whereas in the preceding analyses, the age bias was a second-order factor (i.e., both the side impacts and the control groups are subject to age biases, but are they <u>different</u> age biases?) it is a first-order factor here - the post-standard cars are one year younger than the pre-standard cars and there is nothing that controls for the age difference. Under these circumstances, even a 1 year age difference can substantially bias the results, as the next analysis will confirm.

Evidence of the bias is obtained by extending the sample to include one more model year on each side. Table 6-8 shows the fatality rates, per 1000 vehicle years, during 1975-81, for cars of the first two model years with beams and compares them to the rates for the last two model years without them. Compare the results to Table 6-7. The fatality reduction has escalated from 23 to 29 percent in single vehicle crashes and from 5 to 10 percent in multivehicle crashes.

TABLE 6-8

SIDE IMPACT FATALITY RATES PER 1000 VEHICLE YEARS, DURING 1975-81, IN SINGLE-VEHICLE AND MULTIVEHICLE CRASHES, FIRST 2 YEARS WITH BEAMS VS. LAST 2 YEARS WITHOUT THEM

	Vehicle Exposure Years in 1975-81	Single-Veh. Side Impact Fatalities, 1975-81		Multiveh. Nearside Fatalities, 1975-81	
	(000)	N	Rate	N	Rate
Last 2 model years without beams	84,872	2505	.0295	2541	.0299
First 2 model years with beams	101,270	2137	.0211	2728	.0269
Reduction for post-standard			29%		10%

Now, these findings contrast with the results based on the frontal control group (Sections 6.3.1 and 6.3.2). In the latter, the inclusion of an extra model year on either side hardly changed the result (the single-vehicle fatality reduction increased from 13 to 14 percent; the multivehicle fatality reduction decreased from -7 to -8 percent). Here, however, the results became consistently and substantially more favorable to Standard 214. The vehicle age bias is evidently much stronger in the analysis with no control group.

In order to produce valid results on Standard 214 effectiveness based on fatality rates per 1000 years, an analytic procedure that compensates for the vehicle age bias is obviously needed. The desired procedure is a regression on the fatality rates by vehicle age and other factors.

6.6 Regression of side impact fatality rates per 1000 vehicle years

The procedure that was used for regressions of the proportions of side and frontal impacts (Section 6.4) can also be applied, with minor changes, to the side impact fatality rates per 1000 car years.

As in Section 6.4, the makes and models on FARS are grouped into 7 classes, according to the model year in which beams were first installed. The side impact fatality counts are tabulated in each of these classes by model year (1967-75) and calendar year (1975-81). The number of vehicle exposure years is estimated, by model year and calendar year, for the same 7 classes of vehicles - using the estimation procedure described in Section 6.5. Each fatality count is divided by the corresponding exposure years, yielding a matrix of fatality rates by beam installation class, model year and calendar year.

Past experience in analyzing these types of rates indicates, however, that they do not increase linearly with vehicle age. Instead, the increase in the rate is proportional to the rate itself. Likewise, the reduction in the rate due to a safety device also tends not to be a constant, but rather a percentage of the rate itself. For these reasons, linear regression of the rates is unlikely to produce meaningful results. Instead, the logarithms of the fatality rates should be used as the dependent variables. (See [49] and [71] for further discussion. In fact, linear regressions on the rates were tried and found to assign large spurious benefits to Standard 214.)

Thus, for single vehicle crashes, the dependent variable is

$$\log R_1 = \log \frac{\text{side single-veh fatalities}}{\text{thousands of car years}}$$

For multivehicle crashes, the dependent variable is

$$\log R_2 = \log \frac{\text{multiveh. nearside fatalities}}{\text{thousands of car years}}$$

for a given beam implementation year class, model year and calendar year.

The independent variables are

BEAMS = 1 if beam-equipped, 0 if not beam equipped

AGE = vehicle age = calendar year - model year

T70, T70.5, T71, T72, T73, T73.5 - indicating the model year in which transition to beams was made. For example, T71 = 1 for cars which first attained beams in 1971, = 0 otherwise

CY75, CY76, CY77, CY78, CY79, CY81 - indicating calendar year. For example, CY77 = 1 for 1977 accidents, = 0 otherwise

Over the 7 calendar years studied, AGE ranges from 3-14 for pre-standard cars and from 0-12 for post-standard cars. In other words, the ranges overlap greatly and AGE is not confounded with BEAMS in a manner that would invalidate the regression. Note that AGE^2, which was used in Section 6.4, is not used here: the simpler model $\log R = C_1 \text{ AGE} \pm \ldots$ appears to be adequate for modeling the nonlinear relationship [71]. The regression weight factor for both single and multivehicle crashes is

N = thousands of vehicle years

The regression equation which best fits the observed, weighted data on <u>single-vehicle</u> accidents is

$$
\begin{aligned}
\log R_I = & - 4.553 - .151 \text{ BEAMS} \\
& + .0733 \text{ AGE} \\
& + .49 \text{ T70} + 1.15 \text{ T70.5} + .22 \text{ T71} + .28 \text{ T72} + .54 \text{ T73} \\
& + .30 \text{ T73.5} + .11 \text{ CY75} + .14 \text{ CY76} - .02 \text{ CY77} \\
& + .03 \text{ CY78} + .02 \text{ CY79} - .26 \text{ CY81}
\end{aligned}
$$

and the multiple correlation coefficient is .75 and df = 408. The negative coefficient for BEAMS suggests that Standard 214 is effective - i.e., the side impact fatality rate is lower when BEAMS = 1.

The effectiveness of Standard 214 is readily derived from the model, which formulates the fatality rate $R_1 = R_1$ (BEAMS, AGE, T70, ..., CY81) as a function of BEAMS, AGE, etc. Let $a_1, \ldots, a_{13}$ be an arbitrary set of values for AGE, ..., CY81. "Effectiveness of Standard 214," is always defined by

$$\text{Effectiveness} = 1 - \frac{R_1(1, a_1, \ldots, a_{13})}{R_1(0, a_1, \ldots, a_{13})}$$

$$= 1 - e^{[\log R_1(1, a_1, \ldots, a_{13}) - \log R_1(0, a_1, \ldots, a_{13})]}$$

$$= 1 - e^{-.151}$$

$$= 14 \text{ percent,}$$

regardless of what values $a_1, \ldots, a_{13}$ are assigned to the other independent variables.

This estimate is identical to the one obtained in Section 6.3.2 (comparison of two years before vs. two years after with frontal control group) and just 1 percent higher than the estimates of Sections 6.3.1 and 6.4. Thus, all of the analyses of single vehicle accidents (except for

Section 6.5, where there was uncorrected age bias) consistently produce estimates of effectiveness of 13 or 14 percent.

The standard deviation of the regression coefficient for BEAMS is .053. The null hypothesis that the coefficient is zero can be tested by computing $t = -.151/.053 = -2.85$. Since this quantity is in the critical region of a t distribution with 408 df, the null hypotheses is rejected. As in all previous analyses of single vehicle accidents, the fatality reduction is statistically significant.

The regression equation that best fits the observed, weighted data on <u>multivehicle</u> accidents is

$$\begin{aligned}\log R_2 = & - 4.307 + .0049\ \text{BEAMS} \\ & + .0422\ \text{AGE} + .05\ \text{T70} + .40\ \text{T70.5} + .13\ \text{T71} - .08\ \text{T72} \\ & + .65\ \text{T73} + .34\ \text{T73.5} + .18\ \text{CY75} + .21\ \text{CY76} + .25\ \text{CY77} \\ & + .30\ \text{CY78} + .14\ \text{CY79} - .23\ \text{CY81}\end{aligned}$$

and the multiple correlation coefficient is .70 and df = 410. The very small positive coefficient for BEAMS suggests that Standard 214 has negligible effect on the fatality rate. Indeed,

$$\text{Effectiveness} = 1 - e^{.0049} = 0 \text{ (i.e., within 0.5\% of zero).}$$

The standard deviation of the regression coefficient is .049, so a confidence interval for effectiveness is given by

$$1 - e^{.0049 \pm 1.645 \cdot .049} = (-9\%, +7\%)$$

Thus, after correcting for the vehicle-age trends, it appears that the introduction of side door beams had no effect on nearside fatality rates in multivehicle crashes. Perhaps, the negative (-4%, nonsignificant) result obtained in the regression using the frontal crash control group (Section 6.4) is attributable to minor anomalies in the control group.

The regressions were rerun on frontal fatality rates, in order to check that the regression model is not attributing spurious "benefits" (or disbenefits) to Standard 214 in frontal crashes. It was reassuring to find that the regression did not attribute any significant effect to Standard 214 in either single or multivehicle frontals. The observed "effects" were 5 percent and 4 percent fatality reductions, respectively, neither of which came close to statistical significance.

6.7 Summary of results

Two basic methods were used for analyzing the effect of Standard 214 on fatalities: (1) Comparison of the ratio of side impact to frontal (control group) fatalities, before and after Standard 214. (2) Comparison of the side impact fatality rate per 1000 vehicle years, before and after Standard 214. Each method, in turn, was applied to simple tabulations of fatalities and as part of a regression model. Alternative tabulations were performed for fatalities one or two years before and after beams were installed. The results, for single vehicle crashes and for nearside occupants in multivehicle crashes, are shown in Table 6-9.

Four estimates of the effectiveness of Standard 214 in single-vehicle crashes appeared to be relatively unbiased: all 3 results using the control group and the regression of fatality rates. Two of them indicated a 14 percent fatality reduction; the other 2, 13 percent. Each of these observed reductions was statistically significant. Since the two estimates of 14 percent were more statistically reliable than the other two (as indicated by the sample size in the tabulation and the multiple correlation coefficient in the regression), 14 percent is the "best estimate" of the overall fatality reduction, due to Standard 214, in <u>single-vehicle</u> side impacts. In Section 6.3.3. empirical confidence bounds were derived for this fatality reduction: 7 to 21 percent.

Since approximately 3400 fatalities would have occurred in single vehicle side impacts during 1980 if Standard 214 had not been promulgated (see Section 11.2.1), the 14 percent fatality reduction corresponds to an annual saving of 480 lives when all cars on the road meet the standard (see Section 11.2.1 for more details).

Only the two regressions appear to have produced unbiased estimates of the effect of Standard 214 on nearside occupants in

TABLE 6-9

FATALITY REDUCTION FOR STANDARD 214: SUMMARY OF FARS RESULTS

	Fataslity Reduction (%)	
	In Single-Vehicle Crashes	Multivehicle Crashes, Nearside Occupants
Based on comparison of side and frontal impacts		
First year with beams vs. last year w/o them	13	-7*
First 2 years with beams vs. last 2 years w/o them	14	-8*
Using regression model	13	-4
Based on side impact fatality rates per 1000 vehicle years		
First year with beams vs. last year w/o them	23**	5**
First 2 years with beams vs. last 2 years w/o them	29**	10**
Using regression model	14	0

*Suspected of bias <u>against</u> Standard 214

**Suspected of bias <u>in favor of</u> Standard 214 multivehicle crashes. The two results were, respectively, a 4 percent fatality increase and no change at all. Even the 4 percent increase did not come close to statistical significance. The regression that showed no change at all had a substantially higher multiple correlation coefficient. The FARS results are highly consistent with the hypothesis that Standard 214 has little or no effect on fatalities in multivehicle crashes.

Chapter 7 presents analyses of National Crash Severity Study data on life-threatening (AIS $\geqslant 4$) injury reduction which are consistent with the FARS results on fatalities.

Chapters 9 and 10 explore NCSS and FARS data to seek reasons why Standard 214 reduced fatalities in single-vehicle crashes, but not multivehicle crashes.

CHAPTER 7

SERIOUS INJURY REDUCTION FOR STANDARD 214: ANALYSES OF NCSS DATA

Since 1977, the National Crash Severity Study (NCSS) has been a primary source of detailed information on vehicle and injury performance in highway accidents involving passenger cars. NCSS is a probability sample of 12,050 towaway accidents which occurred during 1977-78 and were investigated by multidisciplinary teams. The data are used to evaluate the reduction in hospitalizing injuries attributable to Standard 214. The analysis method is similar to that used in the evaluation of energy-absorbing steering columns ([44], pp. 138-197).

The analyses of this chapter show that Standard 214 has significantly reduced the risk of hospitalization in single vehicle side impact crashes. The reduction is about 25 percent, corresponding to an annual prevention of 5000 hospitalizations. The benefits are not limited to occupants sitting on the side of the car that was damaged nor to crashes in which the door is the focal point of the damage - in fact, Standard 214 appears to lessen injury risk in nearly all types of single-vehicle side impact crashes.

The analyses also show that Standard 214 has significantly reduced the risk of hospitalization in multivehicle side impact crashes but primarily for occupants seated adjacent to a door which was the center point of the impact damage. The reduction for these occupants is about 25 percent, corresponding to an annual prevention of 4900 hospitalizations. In impacts not centered on the doors and for occupants not sitting next to a struck door, the benefits of Standard 214, if any, appear to be negligible.

7.1 NCSS overview, definitions and analysis methods

Seven multidisciplinary accident investigation teams collected the NCSS data during 1977-79 under contract to NHTSA. The geographical areas in which they worked were chosen by NHTSA to represent the United States as a whole, both in terms of regional and rural/urban distribution. Each team selected accidents for investigation within its area according to a strict probability sampling scheme. The sampling frame included all police-reported automobile towaway accidents - i.e., crashes in which at least one passenger car was towed from the scene due to crash damage. NCSS investigators supplemented the police report with their own investigations of vehicle exterior and interior damage and obtained injury information from medical records and driver interviews.

A detailed description of NCSS may be found in [44], pp. 138-148, and in [65].

The effectiveness of Standard 214 is the relative difference in the injury rates, per 100 side-impact involved occupants, in pre- and post-standard cars. In order to calculate injury rates, it is necessary to know:

(1) How many persons were involved in "side" impacts

(2) How many of them rode in cars meeting Standard 214

(3) How many of them were "injured."

7.1.1 Definition of side impact and nearside/compartment impact

NCSS data include a Collision Deformation Classification [12], whose first letter indicates the general area of damage. Side impacts are defined here to be vehicles whose primary damage is on the left or right side - the first letter of the primary CDC is L or R - but excluding rollovers resulting in side damage (first letter L or R and 4th letter O). This definition differs from the FARS analyses (Chapter 6) and the 1979 report [46], which did not exclude side damage rollovers. Also excluded from the present NCSS analysis are convertibles, El Caminos and Rancheros - the first, because they are no longer sold in significant numbers; the others, in order to confine the study to "pure" passenger cars.

The preceding definition includes all car occupants in all side impacts. Protection from intrusion, however, is thought to be especially important for the occupant sitting adjacent to a door that was damaged. Some of the analyses will focus on these "nearside occupants in compartment impacts," who are defined as follows:

A left front or left rear seat occupant is a nearside occupant if the damage is on the left side; the right front and right rear occupants are nearside if the damage is on the right. All other occupants, including those in center seats, are called "farside" in this study.

A compartment impact is one whose damage is centered in the car's front door area. On the NCSS File, the centerpoint of the damage is given by the variable V1IMPDD, which is the "D" input parameter to the CRASH program ([65], p. 5-28, [54]). Based on measurements of a variety of cars, it was found that impacts with V1IMPDD in a range of -15 to + 45 inches are centered on, or at least very substantially overlap with the front door. Note that this definition is quite a bit more restrictive than those of earlier studies, which were based on the 2nd letter of the CDC being P, D, Y or Z. The earlier definition allowed many impacts which just minimally involve doors to be classified as "compartment impacts." (The older definition, however, is used for the 18 percent of the NCSS side impacts for which V1IMPDD is unknown.)

7.1.2 Definition of pre- and post-Standard 214

Table 4-1 lists, by make and model, the model year in which side door beams were first installed. Cars of that model year or subsequent years are defined to be "post-standard" in the NCSS analysis; earlier cars are pre-standard. For cars that were constructed with beams in mid-model years (Camaros, Firebirds and most Chrysler and VW products), that change-over year is excluded from the study. On NCSS, the make and model is usually identified by the 5 digit make/model code ([65], pp. 8-8 - 8-20). In the case of 1970 Chargers and Challengers, which have the same code but differ in terms of Standard 214 compliance, it was necessary to break down the VIN (see Appendix B) to see which were which.

Foreign cars, except VW's, are not listed on Table 4-1. It is not known exactly when beams were installed in various models. The scanty information that is available [11], suggest dates varying from mid-1972 through mid-1973. The present NCSS analysis uses a conservative approach: cars from 1971 and earlier are pre-standard; 1974 and later, post-standard; and 1972-73 imports are excluded from the analysis.

7.1.3 Definition of injury

The injury criterion in most of this chapter is hospitalization. An occupant was transported to be "hospitalized" if he was killed or was transported from the scene (according to the police report) and then hospitalized (WEIGHTFA = 1 and NCSSCLAS = 1-4). In NHTSA's evaluation of the steering column [44], pp. 146-149, this injury criterion was chosen in preference to AIS-based schemes [1] because missing data are eliminated and because it greatly enhances statistical precision when used with the NCSS sampling scheme.

Section 7.7 however, focuses on more serious injuries: the fatalities and the AIS $\geqslant$ 4 (life-threatening) nonfatal injuries.

7.1.4 Preview of analysis methods

The first step in the analysis is to calculate the injury rates for occupants of pre-Standard 214 cars involved in side impacts and also for post-Standard 214 cars. The injury rate is the number of injured persons per 100 crash-involved occupants.

In this context, it is important to note that NCSS is not a simple random sample. It is a stratified random sample with 4 strata, whose sampling proportions are 100, 25, 10 and 5 percent, respectively [65]. In order to produce valid estimates for the universe of accidents that NCSS is drawn from, it is necessary to weight each NCSS case by the inverse of the sampling fraction, i.e., by a factor of 1, 4, 10 or 20 for the 4 respective strata. All NCSS tabulations in this report, except where specifically noted otherwise, are weighted counts and all injury rates are based on weighted data.

The injury rates are calculated using the preceding definitions of side impact, pre- and post-Standard 214, and injury (7.1.1 - 7.1.3). Note that all injured persons, by the definition used in Section 7.1.3, are in the 100 percent sampling stratum - i.e., the weighted and unweighted counts of injured persons are equal. A <u>preliminary estimate</u> of the effectiveness of Standard 214 is obtained by calculating the reduction of the post-standard injury rate relative to the pre-standard rate (Section 7.3). Since three types of side impacts were defined in Section 7.1.1, three effectiveness estimates are obtained, viz.

(1) In single-vehicle crashes

(2) In multivehicle crashes

(3) For nearside occupants in multivehicle crashes with damage centered on the passenger compartment.

It is likely, though, that the preliminary estimates are biased due to <u>age effects</u> - i.e., differences in the occupants, vehicles and crashes of pre- and post-standard cars that are not due to Standard 214 but only to the fact that the pre-standard cars are older: part of the observed injury reduction may be due to safety devices (other than beams) which may be present in all the newer cars but only in some of the pre-Standard 214 cars. Another part may be due to underreporting of noninjury accidents involving older cars - resulting in spuriously high injury rates for the older cars and a spurious reduction for post-Standard 214 cars.

The preliminary estimates may also be biased due to towaway criterion effects. NCSS is a towaway file. A modification in the vehicle structure could affect whether a crash-involved vehicle can be driven or needs to be towed - thereby affecting its presence or absence from the NCSS file. If side door beams reduce the need for towing a vehicle in relatively minor crashes, the post-Standard 214 cars on NCSS will have more severe crashes and a spuriously higher injury rate than the pre-standard cars. Likewise, side structure characteristics not directly related to Standard 214 (pillars, number of doors, frame type) could affect NCSS injury rates if they increase or reduce the need for towing.

The central part of the analysis is the identification and, where possible, the removal of biases due to the vehicle age and the towaway criterion effects. Four principal analytic techniques are used:

o restricting the age range of the cars under study in order to reduce the age difference between pre- and post-Standard 214 cars. Any such restriction, however, reduces the accident sample size. As Section 7.2

explains, the approach of this chapter is to derive estimates for restricted age ranges (smaller age bias, larger sampling error) and unrestricted ranges (larger bias, smaller sampling error). Specifically, estimates of effectiveness are obtained by comparing injury rates of

(1) Cars of the first two model years with beams versus last two years without them

(2) First five model years with beams versus last five without them

(3) All cars with beams versus all cars without them. (See Section 7.2 for definitions)

Since estimates are obtained for 3 types of side impacts (single veh., multiveh., multiveh. nearside/compartment damage) using 3 age ranges ($\pm$ 2 years, $\pm$ 5, $\pm$ any), a 3 x 3 matrix containing a total of nine preliminary estimates of effectiveness is obtained in Section 7.3.

o Adjusting the injury rates, using control variables and multidimensional contingency table analyses. Suppose that a certain accident variable is significantly correlated with injury risk and also with Standard 214 compliance. For example, safety belt usage decreases injury risk and belt usage is higher in post-standard cars. As a result, part of the injury reduction in post-standard cars is due to the increase in belt usage and should not be attributed to Standard 214. With the aid of multidimensional contingency table analysis, the pre- and post-standard populations are adjusted to have identical marginal distributions of belt usage (the control variable). The injury reduction is recalculated and, since it is not biased by the control variable, it comes closer to measuring the actual effect of Standard 214.

In the evaluation of the energy absorbing steering systems [44], pp. 164-183, a procedure is developed for iterative selection of the control variables that are causing the greatest bias in the injury rate and for adjusting the injury rates using these variables. In Section 7.5, this procedure (with a few minor changes) is applied to <u>each</u> of the <u>nine</u> preliminary estimates of effectiveness to obtain nine <u>refined</u> estimates. The nine refined estimates are the principal statistical results of this chapter. Confidence bounds are also derived for each estimate by a jackknife procedure (described in [44], pp. 187-193).

This analytic procedure can be used for any potential control variable <u>provided that</u> there are some pre-standard <u>and</u> post-standard NCSS cases for each value of the control variable. For example, there are belt users in both pre- and post-standard cars and there are belt nonusers in both types of cars, so "belt usage" is a valid control variable. Thus the procedure can be used for removing biases due to vehicle age-correlated accident characteristics (e.g., rural/urban location, vehicle weight, occupant seat position); due to safety devices whose purchase or usage is optional (e.g., seat belts); and due to some structural features that create towaway criterion effects (e.g., possibly, frame/unitized construction).

This analytic procedure cannot be used, however, if, for some value of the control variable, all cases are pre-standard (or post-standard). For example, any safety device that was mandatory before Standard 214 (e.g., energy-absorbing steering columns) cannot be controlled for, because there are no cars with beams but without EA columns. The procedure cannot be used to control for possible underreporting of noninjury accidents of old cars. It cannot be used with control variables whose values are causally influenced by the presence or absence of beams. For example, if beams reduce crush, the amount of crush is not a valid control variable. The procedure would subtract the injury reduction attributed to the control variable from the effect of Standard 214, whereas, in reality, this injury reduction is a legitimate part of the effect of Standard 214. Section 7.4.4 describes the control variables that cannot be used. Finally, the procedure will not remove the biases, if any, due to a towaway criterion effect of beams themselves.

All of these biases, then, still remain in the refined estimates of Section 7.5 and need to be examined by the two remaining techniques.

- Tabulations of injury rates by model year are useful for detecting gross vehicle age effects such as those due to underreporting of noninjury accidents of old cars and those due to the introduction of the prinicpal safety devices of 1965-68. These tabulations are discussed in Section 7.4.5. Detailed regressions of injury rates by vehicle age and Standard 214 compliance, however, would be meaningless because of collinearity of these variables and because the NCSS sample is too small for this purpose (see Section 7.2).

o <u>Comparisons of side impacts with frontal crashes</u>. In Section 7.4.7, the numbers of NCSS side and frontal impacts are tabulated by Standard 214 compliance to see if beams reduced the need for towing in side impacts. Since beams can be assumed to have a negligible effect on the need for towing in frontal impacts, a reduction of side impact crashes on NCSS, relative to frontals, could indicate that Standard 214 has reduced the need for towing side-impacted cars.

In Section 7.6, the injury rates in frontal crashes are calculated in a manner corresponding to the basic side impact results (Section 7.3) - i.e., single vehicle vs. multivehicle; pre-Standard 214 vs. post-standard using 3 age ranges.

Finally, in Section 7.8, the results of all of the preceding analyses are compared and discussed. Based on the statistical effectiveness estimates of Section 7.5 with appropriate corrections for biases that could not be removed through the use of control variables, a "best" estimate of effectiveness is derived for each of the three categories of side impacts (single vehicle, multivehicle, nearside occupants in multivehicle compartment crashes). The estimates are compared to the results on fatality reduction obtained in Chapter 6.

7.2 The analyst's dilemma: sample size vs. freedom from bias

In Chapter 6, the very large sample size of FARS made it possible to use an especially unbiased analysis technique: the fatalities in the first model year for which beams were installed were compared to those in the last year in which they were not installed. Restricting the analysis to those two years virtually eliminated vehicle age differences and the effects of safety devices that were installed either before or subsequent to beams. Thus, the fatality reduction could be attributed to Standard 214.

NCSS, on the other hand, does not contain nearly enough side impacts for a statistically meaningful comparison of the last model year before Standard 214 and the first year after.

Chapter 6 also included FARS analyses of a wider range of model years. Since FARS was collected over a span of 7 calendar years, vehicle age and vehicle model year are at least partly independent. It was possible to run a regression with fatality risk as the dependent variable. Standard 214 compliance and vehicle age were separate independent variables. Thus, changes in the fatality risk due to vehicle age differences or safety devices installed before or subsequent to beams were attributed to the vehicle age variable and not to Standard 214.

Since NCSS data, on the other hand, were only collected over a short time span (1977-79), it is not possible to run valid regressions with vehicle age and Standard 214 compliance as separate independent variables.

The analyst's dilemma, then, is to decide what range of model years to consider on NCSS.

At the one extreme, it is possible to compare the injury rate for all post-Standard 214 car occupants to that for all pre-Standard 214 cars. This approach is likely to produce statistically significant differences but, in the absence of a regression by vehicle age, it is uncertain whether the differences are actually due to Standard 214 or to safety devices installed at other times or just vehicle age-related biases.

On the other hand, it is possible to restrict the range of model years used in the analysis and eliminate or reduce the effect of other safety devices and vehicle age differences. But the more the model year range is restricted, the smaller the analysis data set and the less chance there is for statistical significance.

The approach of this chapter is to obtain NCSS results for narrow and wide ranges of model years. Specifically, each effectiveness estimate will be derived three times:

(1) Comparing cars of the first two model years with beams to those of the last two years without beams

(2) First five model years with beams versus last five years without them

(3) All cars with beams versus all cars without beams

If the observed effectiveness is substantial in estimates (2) and (3) but negligible in estimate (1), it is suggested that the injury reduction shown in (2) and (3) may not really be due to Standard 214, but rather to other safety devices or vehicle age differences. Conversely, a large effect found in (1), even if statistically significant, is suspected of being anomalous if it is not confirmed by estimates (2) and (3).

On the other hand, if more or less consistent results are obtained across comparisons (1), (2) and (3), it consititutes the soundest available evidence - although not an ironclad guarantee - that there is a genuine effect and that the effect is due to Standard 214.

The "number of model years before or after beam installation" is defined as follows (refer also to Table 4-1 and Appendix B):

o Most makes and models had beams installed at the beginning of a specific model year. For example, Chevrolet Impalas in 1969. In this example, the first two model years with beams are 1969-70; the last two without them are 1967-68.

o Some had beams installed at mid-year. For example, Pontiac Firebirds in mid-1970. The first two (full) model years with beams are 1971-72, the last two without them are 1968-69.

o Models that never had beams or always had them are grouped with other models of the same corporation and size category. For example, Buick Skylark (GM compact) was first sold in 1975. Since Chevrolet Novas (GM compact) received beams in 1973, it is defined that 1975 is the "third model year with beams" for Skylark as well as Nova.

o 1971 is the "first year with beams" for Chevrolet Vega and Pontiac Astre; 1969 for Pontiac Grand Prix; 1970 for Chevrolet Monte Carlo; 1974 for Chrysler Cordoba.

o Foreign cars (other than VW) have uncertain dates of initial beam installation. They are <u>excluded</u> from the data used in comparisons (1) and (2). In comparison (3), model years 1971 and earlier are included in pre-standard; 1974 and later in post-standard.

o Special definitions apply to Dodge Chargers, which were intermediate specialty cars through 1970 and intermediates (not specialty) beginning in 1971.

7.3 Preliminary effectiveness estimates - based on tabulations of the raw data

Table 7-1 provides injury rates in single vehicle side impacts. For example, there were 169 (unweighted) NCSS occupants of cars of the last 2 model years without beams which had a single vehicle side impact. When each occupant is weighted by the inverse sampling fraction, this amounts to 488 persons. Since 78 of them were killed or hospitalized, the injury rate was 15.98 percent. There were 528 (weighted) persons in cars of the first 2 model years with beams. Only 45 of them were killed or hospitalized, so their injury rate was 8.52 percent. This is 47 percent lower than the preceding injury rate. In other words, the preliminary effectiveness estimate, based on comparison of the first 2 years with beams to the last 2 years without them, is that Standard 214 reduced serious injuries in single vehicle crashes by 47 percent.

Table 7-1 also shows, however, that when the comparison is extended to cars of the first 5 years with beams versus the last 5 without them, the preliminary effectiveness estimate drops to 15 percent.

When the comparison is further extended to include all cars with beams versus all cars without them, the effectiveness rises to 27 percent, about midway between the two preceding results.

The sequence of effectiveness results - 47, 15 and 27 percent - is somewhat puzzling. The 47 percent effectiveness in the 2 year comparison

TABLE 7-1

INJURY RATES IN SINGLE VEHICLE SIDE IMPACTS, BY STANDARD 214 COMPLIANCE, NCSS

Vehicle Age Range	Unweighted Occupants	Weighted Occupants	Hospitalized Occupants	Injury Rate (%)*	Observed Reduction for Standard 214 (%)
Last 2 model years without beams	169	488	78	15.98	
First 2 model years with beams	128	528	45	8.52	47
Last 5 model years without beams	303	1012	137	13.54	
First 5 model years with beams	349	1268	146	11.51	15
All cars without beams	371	1193	178	14.92	
All cars with beams	553	2074	226	10.90	27

*Hospitalized occ./weighted occ.

suggests that beams had an immediate effect and that the positive results are not solely due to other standards or vehicle age factors. On the other hand, the much lower result for the 5 year comparison (with over double the sample size) might suggest that the 2 year result is, in part, a statistical accident. In general, the preliminary estimates suggest that beams may have been beneficial in single vehicle crashes but a detailed analysis of possible biases is needed before effectiveness can be reliably estimated.

Table 7-2 provides the injury rates in <u>multivehicle</u> side impacts. The preliminary effectiveness estimates are:

- 5 percent in the 2 year comparison
- 15 percent in the 5 year comparison
- 14 percent in the all-year comparison

These preliminary results tend to indicate that effectiveness in multivehicle crashes, if any, is considerably lower than in single vehicle crashes. They do not exclude the possibility that effectiveness is negligible and that the gradually increasing positive results may be due to vehicle age differences and other standards. Again, a detailed analysis of biases is needed.

Table 7-3 also deals with multivehicle crashes but is limited to <u>nearside</u> occupants of cars whose damage was centered in the passenger

TABLE 7-2

INJURY RATES IN MULTIVEHICLE SIDE IMPACTS, BY STANDARD 214 COMPLIANCE, NCSS

Vehicle Age Range	Unweighted Occupants	Weighted Occupants	Hospitalized Occupants	Injury Rate (%)*	Observed Reduction for Standard 214 (%)
Last 2 model years without beams	672	2818	179	6.35	
First 2 model years with beams	863	3633	219	6.03	5
Last 5 model years without beams	1210	5010	335	6.69	
First 5 model years with beams	1918	8274	473	5.72	15
All cars without beams	1599	6576	455	6.92	
All cars with beams	2871	12345	733	5.94	14

*Hospitalized occ./weighted occ.

compartment. It shows positive and nearly identical effectiveness for Standard 214 in all 3 comparisons:

- o 22 percent in the 2 year comparison
- o 22 percent in the 5 year comparison
- o 25 percent in the all-year comparison

The preliminary results give a fairly strong indication that beams are effective in the situation for which they were primarily designed (nearside occupants in vehicle-to-vehicle compartment crashes). Analyses of biases are needed to sharpen the effectiveness estimates.

TABLE 7-3

NEARSIDE OCCUPANT INJURY RATES IN MULTIVEHICLE IMPACTS CENTERED ON THE PASSENGER COMPARTMENT, BY STANDARD 214 COMPLIANCE, NCSS

Vehicle Age Range	Unweighted Occupants	Weighted Occupants	Hospitalized Occupants	Injury Rate (%)*	Observed Reduction for Standard 214 (%)
Last 2 model years without beams	145	444	70	15.77	
First 2 model years with beams	173	571	70	12.26	22
Last 5 model years without beams	262	831	118	14.20	
First 5 model years with beams	376	1353	149	11.01	22
All cars without beams	329	1044	153	14.66	
All cars with beams	576	2108	232	11.01	25

*Hospitalized occ./weighted occ.

7.4 Sources of bias in the preliminary estimates

The preview of analysis methods (Section 7.1.4) listed the major sources of potential bias in the preliminary effectiveness estimates. Each of these is now discussed in detail. Specifically identified are biases which can be removed by the use of control variables and multidimensional contingency table analyses. These analyses yield refined effectiveness estimates in Section 7.5. Biases that cannot be removed by use of control variables are analyzed in this section.

7.4.1 Safety standards other than Standard 214

Section 4.4.1 identified Standards 201 (interior protection), 203 (steering control impact protection), 205 (glazing materials), 206 (door locks), 208 (safety belts) and 216 (roof crush resistance) as the standards (other than 214) most likely to have significant benefits in side impacts. The safety devices associated with those standards (except 216) were generally installed during 1965-68, usually several model years before side door beams. The Standard 216 modifications, in most cars, came several years after beams.

Table 7-4 shows the actual percentages of side-impacted cars on NCSS satisfying Standards 201, 203, 205, 206 and 216 and the actual percentage of persons involved in NCSS side impacts who were wearing belts. For example, 84 percent of the pre-Standard 214 cars met the requirements of Standard 201; belt usage was 8 percent in the pre-Standard 214 cars. But in the last 2 model years before beams were installed, 96 percent of the cars met Standard 201 and 100 percent met Standards 203, 205 and 206.

TABLE 7-4

PERCENT OF CARS COMPLYING WITH STANDARDS 201, 203, 205, 206, AND 216; PERCENT OF OCCUPANTS USING SAFETY BELTS, NCSS

FMVSS	Pre-Standard 214			Post-Standard 214		
	All MY	Last 5 MY	Last 2 MY	First 2 MY	First 5 MY	All MY
201 (interior protection)	84	91	96	100	100	100
203 (steering column impact)	84	92	100	100	100	100
205 (windshield glazing)	88	97	100	100	100	100
206 (door locks)	91	99.7	100	100	100	100
216 (roof crush resistance)	0	0	0	20	40	60
Safety belt usage	8	7	8	7	10	11

It is obvious from Table 7-4 that the overwhelming majority of pre-Standard 214 cars on NCSS complied with Standards 201, 203, 205 and 206. A majority of cars of the first 5 model years with beams did not comply with Standard 216. As a result, relatively little of the difference in injury rates between pre- and post-Standard 214 cars can be attributed to those other standards. For example, even if those five standards, together, reduced injury risk in side impacts by as much as 20 percent (which they probably did not), the reduction in the post-Standard 214 injury rate attributable to those standards is only 5 percent (since only 15 percent of the pre-Standard 214 cars failed to meet 201, 203, 205 and 206, while 60 percent of post-Standard 214 cars met 216). That is the maximum bias in the all-year comparison. In the 5 year comparison, it is half as large and in the 2 year comparison it is virtually nil. Compliance with Standards 201, 203, 205, 206 or 216 cannot be introduced as a control variable in Section 7.5 because all post-Standard 214 cars meet those earlier standards. Therefore, it is necessary to rely on the preceding heuristic assessment of bias.

Table 7-4 shows that belt usage is 3 percent higher in post than in pre-Standard 214 cars (but only in the 5-year and all-year comparisons). Belt usage, however, is a valid control variable because it is never 0 nor 100 percent for either pre- or post-standard cars. In fact, belt usage is selected as one of the important control variables in nearly all of the 5-year and all-year comparisons (in Section 7.5.2) and, in each case, controlling for belt usage results is an estimate of Standard 214 effectiveness that is lower by several percent.

7.4.2 Vehicle modifications not mandated by safety standards

Section 4.4.3 provided a year-by-year history of major changes in car design from 1965 (the earliest year for which there are substantial numbers of NCSS cars) to 1978 (the latest year on NCSS). Car design changed relatively little in that period: the introduction of compact and intermediate cars took place before 1965, whereas downsized and front-wheel-drive cars were just beginning to appear in 1977 and 78. The most noteworthy changes that had possible safety implications in side impacts were:

- Domestic subcompacts appeared in 1971
- A gradual weight increase within size classes through 1976, with a compensating market shift to lighter size classes.
- A gradual shift from pillarless hardtops to pillared "hardtops."
- Intermediate Fords and Mercurys changed from unitized to body and frame construction in 1972
- Convertibles were gradually eliminated.

Very few changes directly coincided with the installation of side door beams. In fact, Section 4.4.3 showed that beam installation usually did not coincide with major redesign years. The only important exceptions were the intermediate Fords and Mercurys, which got beams when they changed to body and frame construction, the Chevrolet Vega which had beams from the start, and the Pontiac Firebird and Chevrolet Camaro, which received beams and B-pillars at the same time. These cars accounted for about 10 percent of sales. In the other models, beams were typically installed as part of relatively minor body (Ford) or sheet metal (GM) changeovers or in the middle of a run (Chrysler, AMC and imports). Also, the big changeover from genuine to pillared hardtops - which was especially noticeable on GM intermediates and Chrysler compacts - took place 3 or more years <u>after</u> beams were installed.

In other words, if a substantial injury reduction took place immediately upon the implementation of Standard 214, it can be attributed principally to the standard and only minimally to structural changes that coincided with the standard. Similarly, in a comparison of the first 2 model years with beams to the last 2 without them, relatively little of the observed injury reduction can be due to vehicle modifications that took place within a year of beam installation.

Over a longer term comparison, such as the first 5 model years with beams versus the last 5 without them, structural modifications could significantly bias the preliminary estimates of Standard 214 effectiveness. Fortunately, the major structural modifications are all valid control variables. Their potential biases can be and are identified and removed in the analyses of Section 7.5. For example, the presence or absence of B-pillars is a valid control variable, because many pillarless cars continued to be produced after Standard 214.

The control variables that are used to account for nonmandatory structural modifications are

- o B-pillar: present or absent
- o Body structure: body and frame vs. unitized or integral
- o 2 doors or 4 doors
- o vehicle weight

These control variables are needed not only because of the longterm shifts in car design but also because of the way in which Standard 214 was implemented. The first cars to receive beams were the larger GM and Ford products, which were far more likely to have body-and-frame construction, somewhat more likely to have 4 doors and, of course, were heavier than the average car. The pre-standard larger GM and Ford cars are, on the average, older than other pre-standard cars and, therefore, underrepresented in NCSS. As a result, post-Standard 214 cars on NCSS are somewhat more likely to have body-and-frame construction, 4 doors, and a higher weight than pre-standard cars. Since only about 3 percent of the pre-standard cars and virtually none of the post-standard cars were convertibles, the bias due to the shift in production of convertibles cannot be accounted for by a valid control variable. Instead, the bias is eliminated by removing convertibles from the data file - the data loss is minimal.

7.4.3 Vehicle age biases that can be removed by control variables

Older cars have a somewhat different crash environment from newer cars and this can affect injury rates. As a result, the preliminary injury reductions for Standard 214 may in part be attributable to vehicle age differences. For example, since rural accidents have a higher injury risk than urban ones, if pre-standard cars are overrepresented in rural areas, the pre-Standard 214 injury risk would be biased upwards. So would the preliminary effectiveness estimate.

Many age-related differences in the crash environment can be specifically identified and removed by use of control variables. Some valid control variables than can be and are used with NCSS in Section 7.5 are

- Rural/urban
- Speed limit
- Size of the striking vehicle (in multivehicle crashes)
- Nearside/farside (occupant seat position relative to damage)
- Occupant age
- Occupant sex

These control variables are used in addition to vehicle weight and belt usage, which were discussed in the preceding sections. They are valid control variables because, for example, there are both rural and urban crashes involving pre-standard cars and there are both rural and urban crashes involving post-standard cars.

The above list of variables conspicuously omits Delta V, principal direction of force and some other controls widely used in the literature. They are not valid control variables for the evaluation of Standard 214, as will be shown in the next section.

7.4.4 Some invalid control variables

In Section 7.1.4, it was shown that a prerequisite for a valid control variable is that its values are causally independent from whether or not a car meets Standard 214. After all, the analysis finds the injury reduction attributable to differences in the distribution of the control variable and subtracts it from the effect of Standard 214. But if those differences are themselves a consequence of Standard 214, their effect on injury rates should not be subtracted from the effect of Standard 214.

The problem arises with measures of crash damage and, more generally, measures of crash severity that are partly based on damage. Since Standard 214 is a structural modification, it may alter patterns of damage.

Specifically, Section 9.3.2 shows that Standard 214 significantly changed crush patterns in single-vehicle crashes. Crush became, on the average, 2 inches (i.e., 20%) less deep and 10 inches wider, immediately upon installation of beams. Damage that started in the passenger compartment became more likely to spread to the rear fender areas rather than remain concentrated in the compartment. On the other hand, damage that started in the front fender areas was sometimes contained in that area and prevented from spreading to the compartment. As a result, there was a substantial reduction in crashes with damage centered in the compartment, relative to crashes with damage centered outside the compartment (see Section 9.4). Finally, there may have been a lower incidence of damage to the greenhouse area of the passenger compartment (9.7).

Damage patterns were also modified in multivehicle crashes, especially if the impact was centered in the compartment, but the changes were much less than in single vehicle crashes. Crush depth was reduced by 1-2 inches, while its width was increased by a few inches. There was, however, no change in the proportion of crashes with damage centered in the compartment. Finally, post-standard cars had a somewhat lower incidence of sill override. (see Sections 9.3.3, 9.4 and 9.6.)

Therefore, depth of crush is not a valid control variable, since its values were directly affected by Standard 214. Similarly, the trailing numeral of the Collision Deformation Classification [12] - the damage extent zone, which is widely used in the literature as a control - is based on the depth of crush and cannot be used here.

The 2nd letter of the CDC - specific horizontal location - is not a valid control in single vehicle crashes, nor is the centerpoint of the damage (inside or outside the compartment), because Standard 214 affects how the damage spreads out. But they could be used as controls in multivehicle crashes, where this effect is absent. Likewise, it is valid to compare multivehicle compartment crashes of pre- and post-standard cars (as is done throughout this chapter) but not single vehicle compartment crashes.

The 3rd letter of the CDC - specific vertical location - is not a valid control in either type of crash, because Standard 214 might reduce greenhouse involvement in single vehicle crashes while increasing sill involvement in multivehicle crashes.

The principal direction of force (PDOF) is also an unacceptable control variable. The implementation of Standard 214 is accompanied by an immediate increase in the proportion of side impacts which are classified as oblique impacts in NCSS. In single vehicle crashes, the average PDOF became 9 degrees further from perpendicular upon implementation of Standard 214; in multivehicle crashes, 1 degree. This effect seems puzzling at first, because PDOF is theoretically determined by the vehicles' speeds and directions at the instant before contact and should not be affected by crush characteristics. A possible explanantion is that, in real-life accident investigation, the velocity vectors at impact are unknown and must be reconstructed from available evidence. Part of that evidence is the struck vehicle's damage pattern. Since Standard 214 has caused damage to be shallower and wider, it could create the impression that the contact took place at a relatively more oblique angle. While this may not be a complete explanation, it does lead to questions about the validity of using PDOF as a control variable. (See Section 9.5.)

Finally, Delta V is not a valid control. It is measured on NCSS by means of the CRASH program [54], which relies, in the overwhelming majority of cases, heavily or exclusively on PDOF and the crush measurements, which are themselves not valid controls. Observed Delta V declined, on the average, by 1 mile per hour (about 10 percent) in single vehicle crashes upon implementation of Standard 214.

7.4.5 Other vehicle age-related biases

There is also, possibly, an additional "age effect" due to underreporting of noninjury crashes involving older cars. If many non-injury crashes of old cars are unreported, there would be a higher injury rate among those crashes which are reported. This phenomenon is prevalent in State data files, where minor property damage crashes of old cars are not reported because they fail to meet the legal reporting criterion for value of the damage [15].

A major advantage of the towaway criterion on NCSS is that the file is limited to a more severe category of crashes: only 25-35 percent of police-reported, crash-involved vehicles are towaways [63]. Relatively few towaways escape the legal reporting criteria, so not much of an age effect due to underreporting would be expected on NCSS.

Vehicle age-related reporting biases cannot be identified or removed through the use of control varaibles. Instead, NCSS injury rates are tabulated by model year and inspected to see if there are any trends. (Since the NCSS data were collected in 1977-78, vehicle age approximately equals 77.5 minus model year.) This approach was used in the steering column evaluation to examine the trends in the steering-assembly contact injury rate. No age-related trend was found in that study.

Table 7-5 shows the NCSS injury rates, by model year, in single vehicle side impacts. For example, in cases of model years up to 1966, the injury rate was 19 percent. The NCSS sample sizes are too small to give a really precise picture of the injury rate trend, even when the model years are grouped, as in Table 7-5, to enlarge the sample for each data point. (The sample sizes shown in the Table are weighted counts, so the variance is greater than pq/N.) The following observations, therefore, are somewhat tentative:

o There was no downward trend in the injury rates prior to Standard 214. The rate for 1967-68 (23%) is actually higher than for 1966 and earlier cars (19%). Noninjury towaways of cars 12 or more years old (1966 and earlier) would not appear to be seriously underreported.

o The big dropoff of injury rates coincides with the installation of beams in 37 percent of the vehicle fleet. The rate dropped from 23 percent in 1967-68 to 11 percent in 1969-70. Of course, part of this large drop could be due to chance or to an underreporting of the 1967-68 non-injury cases.

TABLE 7-5

INJURY RATES IN SINGLE VEHICLE SIDE IMPACTS, BY MODEL YEAR, NCSS

Model Years	N of Occupants	Injury Rate (%)	Comments	
66 and earlier	227	19	Pre-FMVSS era	Before Std. 214 implementation
67-68	215	23	Meeting major FMVSS	
69-70	609	11	Beams in 37% of fleet	Std. 214 implementation years
71-72	523	13	Beams in 61% of fleet	
73-74	568	11	Beams in 100% of fleet	
75-76	536	12		Post-implementation years
77-78	589	8		

o The injury rate for 1975-76 (12%) is slightly higher than for 1973-74 (11%). Thus, injury rates did not continue to drop after the installation of beams had been completed fleet-wide. On the other hand, the injury rate was lower in 1977-78 (8%), possibly indicating a trend in the newest cars on NCSS.

The injury rates in Table 7-5 are consistent with a hypothesis that reporting biases are minimal and that the big dropoff in injury rates is mainly due to Standard 214. But, due to the relatively small samples, they by no means constitute proof of the hypothesis.

Table 7-6 shows injury rates by model year in multivehicle side impacts. The injury rates are based on larger samples and are more precise than the ones for single vehicle crashes. On the other hand, since the effect of Standard 214 is smaller, it is no easier to isolate this effect from vehicle age trends.

o The injury rate is nearly flat from 1967-68 onwards. It is 7 percent in 1967-68 and 1977-78 and 6 percent in all the years in between. From 1967 onwards, then, there is little or no vehicle age bias, but the potential effect of Standard 214 does not appear too large, either.

o The injury rate for 1966 and earlier cars (9%) is higher than for 1967-68 (7%). This could reflect a reporting bias for the oldest cars,

TABLE 7-6

INJURY RATES IN MULTIVEHICLE SIDE IMPACTS, BY MODEL YEAR, NCSS

Model Years	N of Occupants	Injury Rate (%)	Comments	
66 and earlier	1496	9	Pre-FMVSS era	Before Std. 214 implementation
67-68	1637	7	Meeting major FMVSS	
69-70	2984	6	Beams in 37% of fleet	Std. 214 implementation years
71-72	3159	6	Beams in 61% of fleet	
73-74	3509	6	Beams in 100% of fleet	
75-76	3517	6		Post-implementatior years
77-78	2619	7		

_or_ it could indicate the effect of the major 1967-68 safety standards, _or_ it could be due to chance. At any rate, the biggest observed drop in injury rates is during the pre-Standard 214 era.

The injury rates in Table 7-6 are fairly strong evidence that reporting biases are minimal _after 1967_. They suggest that Standard 214 effectiveness estimates based on cars of the last 2 or even the last 5 model years before beam installation will be more or less free of this type of bias. The comparison of all pre- vs. all post-Standard 214 cars, on the other hand, could be biased.

7.4.6 _Towaway criterion biases that can be removed by control variables_

A major advantage of the towaway criterion on NCSS, as has just been shown, is that age-related reporting biases are minimized. A disadvantage is that injury rates could be biased by modifications in the vehicle structure that affect whether a crash-involved car can be driven or needs to be towed. If a structural feature reduces the need for towing in relatively minor (mostly noninjury) crashes, the cars with this feature that do need towing will represent, on the average, a more severe class of crashes than the cars without it and they will have spuriously higher injury rates.

Vehicle size is an important structural feature that affects the need for towing. Under similar crash circumstances, bigger cars are less likely to need towing - thus, their injury rates are spuriously increased on NCSS. Since post-Standard 214 cars are, on the average, heavier than older cars, this creates a bias against Standard 214 in the preliminary effectiveness estimate. This bias, however, can be identified and removed by using vehicle size as a control variable - analytically, there is no difference in using control variables to correct vehicle age biases (Section 7.4.3) and towaway criterion biases. (Vehicle size actually causes 2 biases: a towaway bias against Standard 214 and a bias in the opposite direction because size increases reduce injury risk in crashes. They nearly cancel each other out; as a result, vehicle size never turns out to be an important control variable in Section 7.5).

There are other structural features that affect the need for towing, but only in single vehicle side impacts. Above all, cars of body and frame construction have a much lower towaway involvement rate than cars of the same size of unitized or integral construction. The number of NCSS cases of single vehicle side impacts, relative to nationwide sales, is 50 percent lower for full-size and intermediate GM cars and full-sized Fords (body and frame) than for full-size and intermediate Chrysler products (integral). (In multivehicle side impacts, by contrast, the involvement rates are nearly identical.) It is not exactly clear why this effect occurs - it could even be a towaway-resistant feature of big GM and Ford cars (the only body and frame cars after 1965) that has nothing to do with the fact that they have frames - although it is not implausible that body and frame cars would be more damage resistant in collisions with fixed objects, where the sill is almost immediately engaged.

To a lesser extent, the presence of B pillars and/or 4 doors reduces the need for towing in single vehicle side impacts. (Of course, many 4 door cars are also of body and frame construction. But the towaway-resistant effect appears to be there independently of the other variable.)

Since heavier cars, body-and-frame construction, B pillars and 4 doors are all overrepresented among the post-Standard 214 vehicle population, they bias the post-Standard 214 injury rate upwards and are causing the preliminary effectiveness estimate for single vehicle crashes to be a substantial underestimate. In Section 7.5, body construction, B pillar, and/or number of doors are always selected as important control variables and always increase the effectiveness estimate in single vehicle crashes. (By contrast, they are only occasionally selected in the multi-vehicle crash analyses. Since they have no effect on the need for towing but do somewhat reduce injury risk, they decrease the effectiveness estimates, there.)

7.4.7 Towaway criterion biases due to Standard 214 itself

If Standard 214, which is a structural modification, affects the need for towing it will bias the NCSS injury rates, just like the other structural features discussed in Section 7.4.6. The bias cannot be removed by the use of control variables because, by definition, there are no post-Standard 214 cars that fail to meet Standard 214.

The possibility of bias is investigated by comparing the NCSS towaway counts in side impacts to the comparable counts in frontal crashes. Since Standard 214 applies to a car's side structure, it should have little effect on the need for towing in frontal crashes. The comparison is perhaps flawed in more recent model years because improved bumper systems may have reduced the need for towing in frontal crashes (causing an increase of side towaways relative to frontals). Therefore, the comparison is limited to the first 3 model years with beams relative to the last 3 without them (full-sized and intermediate GM cars did not get improved bumpers until the 4th year after beams were installed).

Table 7-7 shows the ratio of side to frontal towaways on NCSS in single vehicle crashes. For example, in cars of the last model year without beams, there were 17 single vehicle side impacts for every 100 single vehicle frontal impacts. In the first model year with beams, there were 20 single vehicle side impacts for every 100 single vehicle frontals. Thus, in the one year comparison, side impact towaway involvement increased slightly for post-Standard 214 cars. In the 2 year comparison, however, the situation is reversed. Post-Standard 214 cars have a slightly lower single vehicle side impact involvement rate, relative to frontals (.20), than pre-standard cars (.21). When the comparison is extended to 3 years before and after beam installation, the involvement is again lower for post-standard (.20) than pre-standard (.26).

The results do not suggest that Standard 214 strongly influenced the need for towing in single vehicle crashes. The 3 year comparison, which is

TABLE 7-7

RATIO OF SIDE TO FRONTAL TOWAWAYS, NCSS, BY STANDARD 214 COMPLIANCE, SINGLE AND MULTIVEHICLE CRASHES

	Ratio of Side to Frontal Impacts	
	In Single Vehicle Crashes	In Multivehicle Crashes
Last model year without beams	.17	.60
First model year with beams	.20	.55
Last 2 model years without beams	.21	.52
First 2 model years with beams	.20	.56
Last 3 model years without beams	.26	.56
First 3 model years with beams	.20	.52

based on the largest sample, does suggest that Standard 214 cars were towed about 23 percent less often than pre-standard cars (i.e., the ratio was .20 which is 23% less than .26). But a large portion of this reduction is due to the overrepresentation of body-and-frame, pillared, and/or 4 door cars in the post-standard group, which are less susceptible to towing in side impacts (see Section 7.4.6). Moreover, the 1 and 2 year comparisons do not show a large reduction in towaways for Standard 214, with the 1 year comparison actually showing a slight increase. It is concluded that Standard 214 had no substantial effect on the need for towing in single vehicle crashes.

It is likewise concluded, based on the data in Table 7-7, that Standard 214 had little or no effect on the need for towing in multivehicle crashes. There is no discernable trend in the ratios of side to frontal towaways. The ratio is slightly higher for post-standard cars in the 1 year comparison (.60 vs. .55), lower in the 2 year comparison (.52 vs. .56) and again higher in the 3 year compairson (.56 vs. .52).

7.5 Refined effectiveness estimates - based on multidimensional contingency table analyses

By using control variables and multidimensional contingency table analysis, it is possible to identify and remove biases in the preliminary effectiveness estimates (Section 7.3) that are due to certain differences in the accident environments of pre and post-Standard 214 cars (7.4.3), changes in safety belt usage (7.4.1), and the injury or towaway-reducing effects of vehicle modifications other than Standard 214 (7.4.2 and 7.4.6). The refined effectiveness estimates thereby obtained are the principal statistical results from NCSS. Nine estimates and their confidence boards are obtained: for each of 3 crash types (single vehicle, multivehicle, nearside multivehicle-compartment crashes) over 3 vehicle age ranges (2 years before vs. 2 years after, 5 years, all years).

7.5.1 Procedure

Section 7.1.4 explains, very generally, how control variables are used to remove biases in effectiveness estimates and refers to a procedure for interactive selection of control variables that was developed in the evaluation of steering columns [44], pp. 164 - 183. That procedure, which resembles stepwise regression, is used here with minor changes, and it works as follows:

The starting point is one of the nine preliminary effectiveness estimates in Tables 7-1, 7-2 or 7-3. A list of potential control variables (defined in Section 7.5.2 and discussed in 7.4.1, 7.4.2, 7.4.3 and 7.4.6) is drawn from the NCSS data elements. For each potential control, the 3 way table of Standard 214 compliance by injury by the control variable is formed. The cell entries are smoothed by the BMDP3F multidimensional contingency table analysis [14]. The marginals of the pre and post-Standard populations are adjusted (using the smoothed cell entries) to have the same distribution of the control variable. The injury reduction for post-Standard cars relative to pre-Standard is recalculated using the "expected" cell entries. The control variable which results in the greatest deviation of injury reduction from the preliminary effectiveness estimate is chosen as the first control variable. This is the "first step" of the "stepwise regression." The remaining control variables are scanned. Those which caused less than 1 percent change in the effectiveness estimate are not used in later steps. Also dropped are variables that would, on the next step, produce a table with too many cells for the amount of data available (viz. fewer than 5 injured pre-Standard car occupants per cell).

Next, for each of the control variables still in the running, the 4 way table of Standard 214 compliance by injury by the first selected control by that variable is formed. The cell entries are again smoothed, the marginals adjusted, and the injury reduction recalculated. The control variable which results in the greatest deviation from the previous step is chosen as the second control variable. This is the "second step." The process continues (including scanning of the remaining control variables before the next step) until none of the remaining control variables has an effect as large as 1 percent or until all tables become too large for the amount of data available. If the process ends for the latter reason - and there are still several variables causing more than 1 percent deviation - it may be preferable to choose as the last control variable not necessarily the one which causes the largest deviation but perhaps another one whereby the effects of the unselected variables more or less cancel one another out (this is done only on the multivehicle all-year estimate - see Section 7.5.4).

The injury reduction calculated in the last step is the refined estimate of effectiveness based on NCSS. Its confidence bounds are empirically derived by a jackknife procedure indentical to the one used in the steering column evaluation [44], pp. 187-193. The NCSS sample of crashes under consideration (e.g., single vehicle crashes of cars 2 model years before or after beam installation) is divided into 10 systematic random subsamples of equal size. One subsample is removed and the refined injury rates recalculated for the remaining 9/10 of the sample, using the same control variables and multidiminsional contingency table analysis models as were applied to the full sample. The subsample is returned, another removed, and the injury rates recalculated, etc. The variation found in the 10 calculations is the basis for establishing confidence bounds. The great advantage of the jackknife technique is that it gives an empirical assessment of the effects on variance of the NCSS sampling plan and the particular control variables chosen. These effects can vary considerably from one analysis to another.

The only differences between the process used in the steering column evaluation and the one used here are:

o The initial screening of control variables' 2 and 3 way interactions with FMVSS compliance and injury [44], pp. 170-173, has been omitted here. That screening was mainly a vestige of Hochberg and Reinfurt's analysis process [72] and did not really prove useful in the steering column evaluation.

o The current procedure, on the other hand, allows for deletion of control variables at each step of the iteration. This simplifies the analysis and also deals with a situation (which never occurred in the steering column evaluation) where some variables have too many categories to permit further analysis, but others do not.

o The current procedure allows selection, at the last step, of a variable that does not have the greatest effect on the injury rate if this will allow the effects of the unselected variables to add up to zero. Already, in the steering column evaluation, two variables were tied at the last step: age (effect of -1.3) and sex (+ 1.3) [44], p. 182. The former was chosen because "the trend of the remaining control variables is generally downwards." This rationale, applied in that evaluation to decide ties, is now extended a bit further.

7.5.2 Definitions of the control variables

The following 13 control variables are used:

1. Safety belt usage: yes/no (for discussion see Section 7.4.1)
2. Pillared / true hardtop (7.4.2, 7.4.6)
3. Body and frame / unitized or integral (7.4.2, 7.4.6)
4. 2 doors / 4 doors (7.4.2, 7.4.6)
5. Vehicle weight: light/heavy (7.4.2, 7.4.6)
6. Rural/urban (7.4.3)
7. Speed limit: 55/other (7.4.3)

8. Size of striking vehicle (7.4.3) (n. a. in single vehicle crashes)
9. Nearside/farside occupant (7.4.3) (n. a. in multivehicle nearside/ compartment crashes)
10. Occupant age: young/older (7.4.3)
11. Occupant sex (7.4.3)
12. NCSS team
13. Beam installation year

All control variables must be categorized and, preferably have few categories. Continuous variables (such as age) must be subdivided into class intervals. The definitions and categorizations are as follows (for exact definitions, see Appendix B):

1. Belt usage has 2 values: yes/no (including unknown). Yes includes any type of restraint. The variable is based on the NCSS investigator's belt usage assessment; if this is unknown, then on the interviewee's assessment; if this is unknown, then on the police assessment.

2. Pillared/true hardtop has 3 values: pillared/true hardtop/ unknown. The variable is defined, first, on the basis of make/model/year codes, for those combinations where all cars were of one type. For makes, models and years in which both types of cars exist, the variable is based on a VIN analysis developed for this report. Great care must be used in the VIN analysis, since, in certain years, some pillared cars were called "hardtops" and some pillarless cars were called "coupes" or "sedans." Various information sources were consulted [60],[66],[83] and, when they were inadequate, the variable was left unknown. In the 2 and 5 year comparisons, there were only a few unknown cases and they were combined with the pillared category.

3. Body and frame/ unitized is based on the MDAI manual [60], pp. 43-44. The values shown there are assumed to extend to earlier and later model years on the NCSS file, an assumption partially confirmed by Friedberg[31]. Integral-stubframe is included in the "unitized" category, following Friedberg. There were no unknowns, so the variable has just 2 values.

4. Number of doors has 3 values: 2, 4, unknown. The definition, like hardtop/pillared is based on make/model/year codes followed by a VIN analysis where needed. Hatchback doors are not counted. In the 2 and 5 year comparisons, the relatively few unknowns are combined with the 2 door category.

5. Vehicle weight has two categories: less than 3500 pounds (including a handful of unknowns) /3500 or more. It is based on the weight shown in NCSS. The break was made at 3500 because it is more or less the median weight.

6. Rural/urban has 2 categories: rural/urban, including unknown. Since Delta V, etc. are not valid control variables (see Section 7.4.4), this is an important control for crash severity.

7. Speed limit has 2 categories: 55 / other, including unknown. The speed limit, as used here, is the highest of the speed limits for the various cars in the accident. This is another important control for crash severity.

8. Size of striking vehicle has 4 categories: subcompact or compact car / intermediate or full-size car / light truck / heavy truck. It is based on the NCSS "object contacted" associated with the primary CDC. The variable is important not only as a control for crash severity but also because beam performance is thought to be influenced by the height of the striking vehicles' bumper (see Section 3.2.2).

9. Nearside/farside occupant has 2 values, as defined in Section 7.1.1.

10. Occupant age has 2 values: 24 or less, including unknown / 25 or more. The break is made at the median age on NCSS.

11. Occupant sex has 2 values: male, including unknown/female, including pregnant female and female (unknown if pregnant).

12. NCSS team has 7 values, corresponding to the 7 teams. It was not discussed in Section 7.4. but has been added for several reasons.

o It was the first control variable selected in the evaluation of steering columns. That was primarily due to team-to-team differences in contact point missing data. They are not a factor in the current analysis.

o There could be team-to-team differences in police accident reporting criteria, etc., that could bias effectiveness estimates.

o Another surrogate for crash severity.

This variable is never chosen in any of the analyses.

13. Beam installation year has 8 categories: 69/ 70/ 70.5/ 71/ 72/73 73.5/ unknown. For example, any Plymouth Barracuda (regardless of model year) is in category 70, the year when beams were first installed in this make and model. The variable is a control for vehicle age biases (because cars of the earlier categories are overrepresented among the post-standard group whereas cars of the later categories are overrepresented in the pre-standard group.) It is also added to check whether the effectiveness of beams is reasonably consistent across makes and models. When variable no. 3 has been selected as a control in a previous step, this variable has to be collapsed to 2 categories, 69 - 70.5 and 71 - 73.5, in order to assure both types of body construction are found in each category of the present variable. The "unknown" category, which consists of imported cars other than VW, is absent in the 2 and 5 year comparisons (see Section 7.2).

7.5.3 Effectiveness in single vehicle crashes

The most important control variables in single vehicle crashes are structural features - above all, body and frame vs. unitized construction. As Section 7.4.6 explains, these features affect the need for towing in single vehicle crashes, thereby biasing NCSS injury rates against Standard 214. After controlling for them, the refined effectiveness estimates in single vehicle crashes are always higher then the preliminary estimates of Table 7-1.

Table 7-8 shows the derivation of effectiveness based on a comparison of cars of the first two model years with beams relative to the last two years without them. The starting point is the preliminary effectiveness estimate (from Table 7-1) of 46.7 percent. In Step 1, effectiveness is recalculated 12 times, using each of the control variables separately. When "frame/unitized" is used as the control variable, the effectiveness rises to 53.1 percent, which is an increase of 6.4 percent over the preliminary estimate. This is because body-and-frame cars, which are overrepresented among the post-Standard 214 fleet, are less likely to require towing after a crash and thus have a spuriously higher injury rate. As a result the post-Standard 214 injury rate is also biased upwards. Controlling for that variable reduces the post-Standard 214 injury rate, thereby increasing effectiveness. All of the other variables had effects of lesser magnitude. Therefore, "frame/unitized" is selected as the <u>first</u> control variable.

Another structural feature, N of doors, also increased effectiveness (by 3.3%), but not as much as "frame/unitized." Variables pertaining to crash conditions, such as rural/urban, speed limit, age, sex, etc. resulted in moderate reductions in the effectiveness estimate because, generally speaking,

TABLE 7-8

INJURY REDUCTION ATTRIBUTED TO STANDARD 214 IN SINGLE VEHICLE CRASHES

FIRST 2 YEARS WITH BEAMS VS. LAST 2 YEARS WITHOUT THEM

	Control Variables			Injury Reduction for Standard 214 (%)	Change in Reduction		Disposition of Control Variable
	1st	2nd	3rd		Cumulative	Incremental	
STEP 1	NONE			46.7			
	Belts			43.8	-2.9	-2.9	
	B-pillar			46.8	+0.1	+0.1	X
	Frame/unitized			53.1	+6.4	+6.4	✓
	N of doors			50.0	+3.3	+3.3	
	Veh. weight			47.1	+0.4	+0.4	X
	Rural/urban			43.6	-3.1	-3.1	
	Speed limit			44.2	-2.2	-2.2	
	Nearside/farside			42.8	-3.9	-3.9	
	Occupant age			45.0	-1.7	-1.7	
	Occupant sex			43.5	-3.2	-3.2	
	NCSS team			52.3	+5.6	+5.6	XX
	Beam install. yr.			45.7	-1.0	-1.0	X
STEP 2	Frame/unitized			53.1			
	Frame/unitized	Belts		52.4	+5.7	-0.7	X
	"	N of doors		56.5	+9.8	+3.4	✓
	"	Rural/urban		52.3	+5.6	-0.8	X
	"	Speed limit		53.1	+6.4	0	X
	"	Nearside/farside		51.1	+4.4	-2.0	
	"	Occupant age		54.2	+7.5	+1.1	
	"	Occupant sex		52.6	+5.6	-0.5	X
STEP 3	Frame/unitized	N of doors		56.5			
	Frame/unitized	N of doors	Near/farside	55.3	+8.6	-1.2	✓
	"	"	Occ. age	57.4	+10.7	+0.9	X

✓ selected

X deleted: incremental change 1% or less

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the pre-standard cars had slightly more severe crashes. "Nearside/farside" had the largest effect in this group of variables (-3.9%).

B - pillar, vehicle weight and beam installation year had effects of 1 percent or less because, in the 2 year comparison, the pre and post-Standard populations had about the same distributions of these variables. They are dropped from the list of controls. NCSS team caused a 5.6 percent increase in the estimate but is also dropped: in a 2 year comparison, there are not enough single vehicle crashes to spread out among 7 teams <u>and</u> other control variables. The remaining variables are retained for Step 2.

The starting point for Step 2 is the effectiveness, controlling for frame/unitized, which was derived in Step 1: 53.1 percent. Effectiveness is recalculated 7 times, using frame/unitized as one control and each of the variables remaining after Step 1, separately, as the other control. When N of doors is used as the second control, the effectiveness rises to 56.5 percent, which is an increase of 3.4 percent over the preceding estimate. All of the other variables had incremental effects of lesser magnitude. Therefore N of doors, another structural feature that affects the need for towing, is selected as the <u>second</u> control variable.

Note that the incremental effect of N of doors is virtually the same in Step 2 (3.4) as it was in Step 1 (3.3). This suggests that the biases due to frame/unitized and N of doors are independent and additive. On the other hand, the Step 2 effects of nearside/farside, rural/urban, belt usage, etc. are all diminished from their Step 1 effects. This suggests that these variables are partially correlated with frame/unitized, so the biases are less than additive (e.g., belt usage is lower in body-and-frame cars than in unitized cars because, in this particular situation, the former are older and bigger). This attenuation of effects due to intercorrelation is reminiscent of what occurs in stepwise regression. Specifically, the incremental effects of belts, rural/urban, speed limit and occupant sex are diminshed below the 1 percent level and the variables are dropped from further consideration.

The starting point for Step 3 is the effectiveness controlled for frame/unitized and N of doors: 56.5 percent. Effectiveness is recalculated twice, controlling for frame/unitized, N of doors, and each one of the 2 remaining variables, separately. When nearside/farside is used as the third control, effectiveness drops to 55.3 percent, which is 1.2 percent less than the preceding estimate. This is because farside occupants, who are less vulnerable to injury, are slightly overrepresented (apparently, by coincidence) in the post-standard sample. The other variable, occupant age, has less than 1 percent incremental effect and is dropped from the analysis. No more variables remain, so the analysis is completed, with frame/unitized, N of doors, and nearside/farside selected as controls.

The refined estimate of Standard 214 effectiveness in single vehicle side impacts, based on a 2 year comparison is 55.3 percent. The lower confidence bound (one-sided $\alpha = .05$) for this estimate, based on the jackknife procedure, is 36 percent. The upper bound is 71 percent. The effectiveness is significantly greater than zero (one-sided $\alpha = .05$).

Table 7-9 shows the derivation of effectiveness based on a comparison of cars of the first five model years with beams relative to the last five years without them.

TABLE 7-9

INJURY REDUCTION ATTRIBUTED TO STANDARD 214 IN SINGLE VEHICLE CRASHES

FIRST 5 YEARS WITH BEAMS VS. LAST 5 YEARS WITHOUT THEM

	Control Variables			Injury Reduction for Standard 214 (%)	Change in Reduction		Disposition of Control Variable
	1st	2nd	3rd		Cumulative	Incremental	
	NONE			14.9			
STEP 1	Belts			9.9	-5.0	-5.0	
	B-pillar			16.0	+1.1	+1.1	
	Frame/unitized			24.4	+9.5	+9.5	✓
	N of doors			19.1	+4.2	+4.2	
	Veh. weight			17.3	+2.4	+2.4	
	Rural/urban			11.5	-3.4	-3.4	
	Speed Limit			13.7	-1.2	-1.2	
	Nearside/farside			13.2	-1.7	-1.7	
	Occupant age			14.1	-0.8	-0.8	X
	Occupant sex			13.4	-1.5	-1.5	
	NCSS team			11.8	-3.1	-3.1	
	Beam install. yr.			20.3	-5.4	+5.4	
STEP 2	Frame/unitized			24.4			
	Frame/unitized	Belts		20.9	+6.0	-3.5	✓
	"	B-pillar		27.4	+12.5	+3.0	
	"	N of doors		26.5	+11.6	+2.1	
	"	Veh. weight		22.4	+7.5	-2.0	
	"	Rural/urban		22.1	+7.2	-2.3	
	"	Speed limit		24.4	+9.5	0	X
	"	Nearside/farside		23.7	+8.8	-0.7	X
	"	Occupant sex		24.2	+9.3	-0.2	X
	"	NCSS team		27.4	+12.5	+3.0	XX
	"	Beam install. yr.		24.8	+9.9	+0.4	X
STEP 3	Frame/unitized	Belts		20.9			
	Frame/unitized	Belts	B-pillar	23.6	+8.7	+2.7	✓
	"	"	N of doors	23.2	+8.3	+2.3	XX
	"	"	Veh. weight	19.3	+4.4	-1.6	XX
	"	"	Rural/urban	19.7	+4.8	-1.2	XX

✓ selected

X deleted: incremental change 1% or less

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Again, "frame/unitized" is easily the most influential control variable and is selected in Step 1. This increases the effectiveness by 9.5 percent, from the preliminary 14.9 up to 24.4 percent. The effect of frame/unitized is even larger than in the preceding analysis because body-and -frame cars are even more overrepresented 3-5 years after beam installation than there were in the first 2 years. As in the 2 year comparison, the control variables pertaining to structural features increased the effectiveness estimate while those pertaining to crash conditions decreased it. Two differences from the 2 year comparison are that belts and B-pillars became more important controls. Belt usage significantly increased over the ±5 year period but not over the ±2 year period (see Table 7-4). The largest shifts from hardtops to pillared cars occurred in the 3rd year after beam installation.

Belt usage was selected on Step 2. Control for belt usage reduced the effectiveness from 24.4 to 20.9 percent. At Step 3, B-pillar was selected, having an incremental effect of +2.7 percent. The other 3 variables remaining on Step 3 could not be retained for a possible 4th step, because the tables would have become too large for a valid analysis. Their effects were not large (-1.2, -1.6 and +2.3) and more or less cancelled each other. Thus, the analysis is completed, with <u>frame/unitized</u>, <u>belts</u> and <u>B-pillar</u> selected as controls.

The <u>refined estimate</u> of Standard 214 effectiveness in <u>single</u> vehicle crashes, based on a <u>5</u> year comparison, is 23.6 percent. The <u>lower confidence bound</u> for this estimate is -3 percent; the <u>upper bound</u> is 40 percent. The effectiveness is not significantly greater than zero, although it comes very close to significance.

Table 7-10 shows the derivation of effectiveness based on a comparison of all NCSS cars with beams to all cars without them. What takes place is nearly the same as in the 5 year comparison. Although an influx of foreign cars of unibody construction has somewhat reduced the overrepresentation of body and frame in the post-standard group, "frame/unitized" is still easily the most influential variable and is selected at Step 1. It raises the effectiveness by 7.1 percent, from a preliminary 27.0 to 34.1. Again, belts and B-pillars are the dominant factors in Steps 2 and 3, one negative and the other positive. Only, this time, B-pillar is selected before belts as its Step 2 effect is slightly larger. Belt usage is selected at Step 3. The analysis is completed with frame/unitized, B-pillar and belts selected as controls.

The refined estimate of Standard 214 effectiveness in single vehicle crashes, based on all NCSS side impacts, is 34.1 percent. The lower confidence bound for this estimate is 20 percent; the upper bound is 44 percent. The effectiveness is significantly higher than zero.

The 3 effectiveness estimates (2 year, 5 year and all year) are compared to one another and discussed in light of other bias analyses in Section 7.8.

7.5.4 Effectiveness in multivehicle crashes

Structural features such as body and frame vs. unitized construction are much less influential control variables in multivehicle

TABLE 7-10

INJURY REDUCTION ATTRIBUTED TO STANDARD 214 IN SINGLE VEHICLE CRASHES

ALL CARS WITH BEAMS VS. ALL CARS WITHOUT THEM

	Control Variables 1st	2nd	3rd	Injury Reduction for Standard 214 (%)	Change in Reduction Cumulative	Incremental	Disposition of Control Variable
STEP 1	NONE			27.0			
	Belts			23.1	-3.9	-3.9	
	B-pillar			30.8	+3.8	+3.8	
	Frame/unitized			34.1	+7.1	+7.1	✓
	N of doors			29.3	+2.3	+2.3	
	Veh. weight			30.2	+3.2	+3.2	
	Rural/urban			26.3	-0.7	-0.7	X
	Speed limit			26.7	-0.3	-0.3	X
	Nearside/farside			27.2	+0.2	+0.2	X
	Occupant age			27.1	+0.1	+0.1	X
	Occupant sex			27.0	0	0	X
	NCSS team			24.1	-2.9	-2.9	
	Beam install. yr.			32.3	+5.3	+5.3	
STEP 2	Frame/unitized			34.1			
	Frame/unitized	Belts		30.5	+3.5	-3.6	
	"	B-pillar		37.9	+10.9	+3.8	✓
	"	N of doors		34.5	+7.5	+0.4	X
	"	Veh. weight		33.7	+6.7	-0.4	X
	"	NCSS team		36.3	+9.3	+2.2	
	"	Beam install yr.		35.1	+8.1	+1.0	X
STEP 3	Frame/unitized	B-pillar		37.9			
	Frame/unitized	B-pillar	Belts	34.1	+7.1	-3.8	✓
		"	NCSS team	35.2	+8.2	-2.7	XX

✓ selected

X deleted: incremental change 1% or less

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than in single vehicle crashes. This is because they have little or no effect on whether a car needs to be towed (see Section 7.4.6) and only a moderate effect on injury risk (7.4.2). Instead, the most important control variables pertain to the accident environment, such as the rural or urban location, the speed limit and the size of the striking vehicle. Sometimes the variables create a bias against Standard 214, sometimes in favor. As a result, the refined estimates are neither consistently higher nor consistently lower than the preliminary estimates. But the refined estimates do come closer to one another than the preliminary ones - a good sign that the analysis may have removed biases that caused discrepancies in the preliminary estimates.

Table 7-11 shows the derivation of effectiveness based on a comparison of cars of the first two model years with beams relative to the last two without them.

The only controls that have a substantial effect at Step 1 are the size of the striking vehicle, rural/urban and speed limit. In fact, they turn out to be the 3 selected variables. Note that a large number of variables, including all structural features, are eliminated at the first step: there are relatively few differences in the pre- and post-standard groups over a 2 year comparison.

Size of striking vehicle is selected on Step 1. The post-standard cars are driven in an environment where collisions with trucks, especially

TABLE 7-11

INJURY REDUCTION ATTRIBUTED TO STANDARD 214 IN MULTIVEHICLE CRASHES

FIRST 2 YEARS WITH BEAMS VS. LAST 2 YEARS WITHOUT THEM

	Control Variables			Injury Reduction for Standard 214 (%)	Change in Reduction		Disposition of Control Variable
	1st	2nd	3rd		Cumulative	Incremental	
STEP 1	NONE			5.1			
	Belts			6.4	+1.3	+1.3	
	B-pillar			4.8	-0.3	-0.3	X
	Frame/unitized			4.7	-0.4	-0.4	X
	N of doors			4.5	-0.6	-0.6	X
	Veh. weight			4.9	-0.2	-0.2	X
	Rural/urban			-1.2	-6.3	-6.3	
	Speed limit			7.7	+2.6	+2.6	
	Size of striking veh.			12.0	+6.9	+6.9	✓
	Nearside/farside			5.7	+0.6	+0.6	X
	Occupant age			5.1	0	0	X
	Occupant sex			4.9	-0.2	-0.2	X
	NCSS team			3.5	-1.6	-1.6	
	Beam install. yr.			4.7	-0.4	-0.4	X
STEP 2	Size of striking veh.			12.0			
	Size of striking veh.	Belts		14.4	+9.3	+2.4	
	"	Rural/urban		5.3	+0.2	-6.7	✓
	"	Speed limit		14.1	+9.0	+2.1	
	"	NCSS team		12.0	+6.9	0	X
STEP 3	Size of striking veh.	Rural/urban		5.3			
	Size of striking veh.	Rural/urban	Belts	7.1	+0.2	+1.8	XX
	"	"	Speed limit	11.4	+6.3	+6.1	✓

✓ selected

X deleted: incremental change 1% or less

XX deleted: would have too many cells at next step

large trucks, are more frequent. In that sense, their crash environment is more severe. After control for this bias against the post-standard cars, effectiveness rises from 5.1 to 12.0 percent.

Rural/urban was the second most important variable on Step 1 and is selected on Step 2. Pre-standard cars are more common in rural areas, where crashes are more severe. This is a bias against the pre-standard cars. Controlling for it brings the effectiveness back down to 5.3 percent, barely above the preliminary estimate.

Speed limit is selected on Step 3. The post-standard cars are more likely to have crashes on 55 mph roads. This is a bias against the post-standard cars. Controlling for it takes the effectiveness back up to 11.4 percent. It may seem paradoxical that control for rural/urban is a negative factor but speed limit is positive. The explanation is that, on NCSS, the newer cars are overrepresented in suburbs and primary intercity roads; the older cars on secondary rural roads and inner city streets. Thus, the pre-standard cars are overinvolved in rural areas yet underinvolved on 55 mph roads.

The <u>refined estimate</u> of Standard 214 effectiveness in <u>multivehicle</u> side impacts, based on a <u>2</u> year comparison is 11.4 percent. The <u>lower confidence bound</u> for this estimate is -3 percent; the <u>upper bound</u> is 24 percent. The effectiveness is not significantly greater than zero, although it comes close to significance.

TABLE 7-12

INJURY REDUCTION ATTRIBUTED TO STANDARD 214 IN MULTIVEHICLE CRASHES

FIRST 5 YEARS WITH BEAMS VS. LAST 5 YEARS WITHOUT THEM

	Control Variables 1st	2nd	3rd	Injury Reduction for Standard 214 (%)	Change in Reduction Cumulative	Change in Reduction Incremental	Disposition of Control Variable
STEP 1	NONE			14.5			
	Belts			13.4	-1.1	-1.1	
	B-pillar			14.7	+0.2	+0.2	X
	Frame unitized			14.7	+0.2	+0.2	X
	N of doors			14.1	-0.4	-0.4	X
	Veh. weight			13.1	-1.4	-1.4	
	Rural/urban			9.5	-5.0	-5.0	✓
	Speed limit			18.5	+4.0	+4.0	
	Size of striking veh.			16.8	+2.3	+2.3	
	Nearside/farside			14.6	+0.1	+0.1	X
	Occupant age			15.7	+1.2	+1.2	
	Occupant sex			15.1	+0.6	+0.6	X
	NCSS team			14.2	-0.3	-0.3	X
	Beam install. yr.			15.9	+1.4	+1.4	
STEP 2	Rural/urban			9.5			
	Rural/urban	Belts		7.9	-6.6	-1.6	
	"	Veh. weight		8.4	-6.1	-1.1	
	"	Speed limit		13.6	-0.9	+4.1	✓
	"	Size of striking veh.		12.1	-2.4	+2.6	
	"	Occ. age		10.9	-3.6	+1.4	
	"	Beam install yr.		11.0	-3.5	+1.5	
STEP 3	Rural/urban	Speed limit		13.6			
	Rural/urban	Speed limit	Belts	12.1	-2.4	-1.5	XX
	"	"	Veh. weight	12.4	-2.1	-1.2	XX
	"	"	Size of striking veh.	16.4	+1.9	+2.8	✓
	"	"	Occ. age	15.0	+0.5	+1.4	XX
	"	"	Beam install yr.	15.6	+1.1	+2.0	XX

✓ selected

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Table 7-12 shows the derivation of effectiveness based on a 5 year comparison. The analysis for this much larger sample has nearly the same results as the 2 year comparison. The same control variables are selected, but in a different order: rural/urban at Step 1, then speed limit, then size of striking vehicle. Again, the effect of rural/urban is negative; the other 2 variables have positive effects (although smaller than in the 2 year comparison). The net result is that effectiveness increases only a little: from a preliminary estimate of 14.5 percent to a refined estimate of 16.4 percent. The lower confidence bound for this estimate is 7 percent; the upper bound is 24 percent. The effectiveness is significantly greater than zero.

Table 7-13 shows the derivation of effectiveness based on all NCSS multivehicle side impacts. The addition of a large number of new cars, many of them imports, and a smaller number of quite old cars causes differences from the 5 year comparison. The post-standard cars are not as overrepresented in collisions with large trucks, reducing the effect of size of striking vehicle as a control variable. Differences in belt usage, occupant age and the number of doors are increased.

Speed limit is selected at Step 1, reflecting, as before, overrepresentation of newer cars on 55 mph roads. Effectiveness rises from 14.2 to 18.2 percent. N of doors is the most influential control variable at Step 2: post-standard cars are more likely to have 4 doors, a

TABLE 7-13

INJURY REDUCTION ATTRIBUTED TO STANDARD 214 IN MULTIVEHICLE CRASHES

ALL CARS WITH BEAMS VS. ALL CARS WITHOUT THEM

	Control Variables 1st	2nd	3rd	Injury Reduction for Standard 214 (%)	Change in Reduction Cumulative	Incremental	Disposition of Control Variable
STEP 1	NONE			14.2			
	Belts			12.5	-1.7	-1.7	
	B-pillar			13.7	-0.5	-0.5	X
	Frame/unitized			13.4	-0.8	-0.8	X
	N of doors			12.1	-2.1	-2.1	
	Veh. weight			11.8	-2.4	-2.4	
	Rural/urban			12.8	-1.4	-1.4	
	Speed limit			18.2	+4.0	+4.0	✓
	Size of striking veh.			15.0	+0.8	+0.8	X
	Nearside/farside			14.8	+0.6	+0.6	X
	Occupant age			16.1	+1.9	+1.9	
	Occupant sex			14.0	-0.2	-0.2	X
	NCSS team			15.1	+0.9	+0.9	X
	Beam install. yr.			15.6	+1.4	+1.4	
STEP 2	Speed limit			18.2			
	Speed limit	Belts		16.2	+2.0	-2.0	
	"	N of doors		15.4	+1.2	-2.8	✓
	"	Veh. weight		15.6	+1.4	-2.6	
	"	Rural urban		16.0	+1.8	-2.2	
	"	Occ. age		20.4	+6.2	+2.2	
	"	Beam install yr.		19.7	+5.5	+1.5	
STEP 3	Speed limit	N of doors		15.4			
	Speed limit	N of doors	Belts	12.7	-1.5	-2.7	✓
	"	"	Veh. weight	14.4	+0.2	-1.0	X
	"	"	Rural/urban	12.7	-1.5	-2.7	XX
			Occ. age	18.3	+4.1	+2.9	XX
	"	"	Beam install yr.	16.9	+2.7	+1.5	XX

✓ selected

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structural feature that reduces injury risk. Control for this factor reduces the estimate, by 2.8 percent, to 15.4 percent.

Five control variables survived Step 2 and are tested in Step 3. Three had negative effects: belts, rural/urban and vehicle weight. Only occupant age and beam installation year had positive effects. Although occupant age had the largest effect (+2.9), belts were selected at this step. Their effect was nearly as large (-2.7) and, when they are selected, the effects of the unselected variables nearly cancel each other out. Since it is not feasible to proceed to a fourth step, it is best to pick a variable that has this property. (See Section 7.5.1 for selection criteria at the last step. Rural/urban could also have been selected instead of belts, since it has the same effect.)

After controlling for speed limit, N of doors and belt usage, the refined estimate of effectiveness is 12.7 percent. The lower confidence bound for this estimate is 2 percent; the upper bound is 22 percent. The effectiveness is significantly greater than zero.

7.5.5 Effectiveness for nearside occupants in multivehicle compartment crashes

The analyses for nearside occupants in multivehicle crashes centered on the passenger compartment somewhat parallel the results for all types of multivehicle crashes. But the refined effectiveness estimates are up to 3 times as high. Size of the striking vehicle is the most important control variable. Because the post-standard cars are in all cases overrepresented in collisions with large trucks, the result of controlling for it is to raise the effectiveness estimate. Structural features are relatively unimportant control variables. Belt usage is a major factor in the 5 and all year comparisons.

Table 7-14 shows the analyses for the 2 year comparison. Size of striking vehicle is selected at Step 1 and raises the effectiveness from 22.2 percent to 30.0 percent. Rural/urban and speed limit are also major positive factors on Step 1 and are, in fact, selected on the next 2 steps.

On Step 2, rural/urban and speed limit still have the largest effects, but now in the opposite direction. The change in direction is due to interaction with the first control variable (e.g., post-standard cars are overinvolved in collisions with large trucks, but only in urban areas). Control for rural/urban lowers the effectiveness estimate, by 6.7 percent, back to 23.3 percent.

Speed limit is selected at Step 3. It had a moderate positive effect on Step 1, a small negative effect in tandem with size of striking vehicle and now a positive effect of 10.7 percent in combination with the first 2 controls. The fluctuation is due to interactions of the control variables; moreover, the relatively small sample for this analysis may be exacerbating the variations.

The <u>refined estimate</u> of effectiveness, then, is 34.0 percent in the 2 year comparison. The <u>lower confidence bound</u> for effectiveness is

TABLE 7-14

NEARSIDE OCCUPANT INJURY REDUCTION ATTRIBUTED TO STANDARD 214 IN MULTIVEHICLE IMPACTS CENTERED ON THE PASSENGER COMPARTMENT, FIRST 2 YEARS WITH BEAMS VS. LAST 2 YEARS WITHOUT THEM

	Control Variables			Injury Reduction for Standard 214 (%)	Change in Reduction		Disposition of Control Variable
	1st	2nd	3rd		Cumulative	Incremental	
STEP 1	NONE			22.2			
	Belts			21.7	-0.5	-0.5	X
	B-pillar			19.6	-2.6	-2.6	
	Frame/unitized			22.3	+0.1	+0.1	X
	N of doors			21.2	-1.0	-1.0	X
	Veh. weight			22.3	+0.1	+0.1	X
	Rural/urban			27.1	+4.9	+4.9	
	Speed limit			26.3	+4.1	+4.1	
	Size of striking veh.			30.0	+7.8	+7.8	✓
	Occupant age			22.5	+0.3	+0.3	X
	Occupant sex			20.2	-2.0	-2.0	
	NCSS team			22.1	-0.1	-0.1	X
	Beam install. yr.			23.9	+1.7	+1.7	
STEP 2	Size of striking veh.			30.0			
	Size of striking veh.	B-pillar		28.4	+6.2	-1.6	
	"	Rural/urban		23.3	+1.1	-6.7	✓
	"	Speed limit		27.9	+5.7	-2.1	
	"	Occ. sex		28.6	+6.4	-1.4	
	"	Beam install yr.		31.4	+9.2	+1.4	XX
STEP 3	Size of striking veh.	Rural/urban		23.3			
	Size of striking veh.	Rural/urban	B-pillar	22.9	+0.7	-0.4	X
	"	"	Speed limit	34.0	+11.8	+10.7	✓
	"	"	Occ. sex	21.0	-1.2	-2.3	XX

✓ selected

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13 percent; the upper bound is 51 percent. The effectiveness is significantly greater than zero.

Table 7-15 derives effectiveness estimates for the 5 year comparison. Thanks to the larger sample, the effects of the control variables are more consistent than in the 2 year comparison. Again, size of striking vehicle is selected at Step 1. Effectiveness increases from 22.4 to 29.4 percent. On Step 1, control for belt usage has a moderately large negative effect while rural/urban and speed limit have slightly smaller positive effects.

Belt usage is selected as a control variable on Step 2. Belt users have substantially lower injury rates than nonusers in all types of side impacts, including the ones studied here. As a result, control for belt usage diminishes the effect attributed to Standard 214 by 3.7 percent. Meanwhile, the effects of rural/urban and speed limit drop below the 1 percent level, due to their interaction with size of striking vehicle. B-pillar is the only variable that survives to Step 3, so it is automatically selected. Since B-pillars slightly reduce injury risk, control for their presence reduces the effect attributed to Standard 214 by a further 0.9 percent.

The refined estimate of effectiveness for the 5 year comparison is 24.8 percent. The lower confidence bound for this effectiveness is 10 percent; the upper bound is 38 percent. The effectiveness is significantly greater than zero.

TABLE 7-15

NEARSIDE OCCUPANT INJURY REDUCTION ATTRIBUTED TO STANDARD 214 IN MULTIVEHICLE IMPACTS CENTERED ON THE PASSENGER COMPARTMENT, FIRST 5 YEARS WITH BEAMS VS. LAST 5 YEARS WITHOUT THEM

	Control Variables 1st	2nd	3rd	Injury Reduction for Standard 214 (%)	Change in Reduction Cumulative	Incremental	Disposition of Control Variable
STEP 1	NONE			22.4			
	Belts			17.6	-4.8	-4.8	
	B-pillar			21.1	-1.3	-1.3	
	Frame/unitized			23.2	+0.8	+0.8	X
	N of doors			21.5	-0.9	-0.9	X
	Veh. weight			21.5	-0.9	-0.9	X
	Rural/urban			24.8	+2.4	+2.4	
	Speed limit			25.7	+3.3	+3.3	
	Size of striking veh.			29.4	+7.0	+7.0	✓
	Occupant age			22.9	+0.5	+0.5	X
	Occupant sex			23.1	+0.7	+0.7	X
	NCSS team			24.4	+2.0	+2.0	
	Beam install. yr.			25.3	+2.9	+2.9	
STEP 2	Size of striking veh.			29.4			
	Size of striking veh.	Belts		25.7	+3.3	-3.7	✓
	"	B-pillar		27.9	+5.5	-1.5	
	"	Rural/urban		29.6	+7.2	+0.2	X
	"	Speed limit		28.9	+6.5	-0.5	X
	"	NCSS team		32.3	+9.9	+2.9	XX
	"	Beam install yr.		28.3	+5.9	-1.1	XX
STEP 3	Size of striking veh.	Belts		25.7			
	Size of striking veh.	Belts	B-pillar	24.8	+2.4	-0.9	✓

✓ selected

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Table 7-16 extends the comparison to cars of all ages. Again, size of striking vehicle and belt usage are selected on the first 2 steps, although their influence is a little weaker than in the 5 year comparison. Control for size of the striking vehicle increases the estimate from a preliminary 24.9 up to 30.6 percent; control for belt usage cuts it back to 27.2 percent. Rural/urban has a positive effect on Step 1 which, although diminished in later steps by interaction with size of striking vehicle, is still strong enough for selection in Step 3.

The refined estimate of effectiveness in the all year comparison is 30.0 percent. The lower confidence bound for this effectiveness is 11 percent; the upper bound is 43 percent. The effectiveness is significantly greater than zero.

TABLE 7-16

NEARSIDE OCCUPANT INJURY REDUCTION ATTRIBUTED TO STANDARD 214 IN MULTIVEHICLE IMPACTS CENTERED ON THE PASSENGER COMPARTMENT, ALL CARS WITH BEAMS VS. ALL CARS WITHOUT THEM

	Control Variables 1st	2nd	3rd	Injury Reduction for Standard 214 (%)	Change in Reduction Cumulative	Incremental	Disposition of Control Variable
STEP	NONE			24.9			
STEP 1	Belts			20.9	-4.0	-4.0	
	B-pillar			23.5	-1.4	-1.4	
	Frame unitized			25.4	+0.5	+0.5	X
	N of doors			24.4	-0.5	-0.5	X
	Veh. weight			23.8	-1.1	-1.1	
	Rural/urban			29.4	+4.5	+4.5	
	Speed limit			27.4	+2.5	+2.5	
	Size of striking veh.			30.6	+5.7	+5.7	✓
	Occupant age			26.0	+1.1	+1.1	
	Occupant sex			25.6	+0.7	+0.7	X
	NCSS team			26.1	+1.2	+1.2	
	Beam install. yr.			29.3	+4.4	+4.4	
STEP 2	Size of striking veh.			30.6			
	Size of striking veh.	Belts		27.2	+2.3	-3.4	✓
	"	B-pillar		29.2	+4.3	-1.4	
	"	Veh. weight		29.9	+5.0	-0.7	X
	"	Rural/urban		32.6	+7.7	+2.0	
	"	Speed limit		32.0	+7.1	+1.4	
	"	Occupant age		32.0	+7.1	+1.4	
	"	NCSS team		30.2	+5.3	-0.4	X
	"	Beam install yr.		32.8	+7.9	+2.2	XX
STEP 3	Size of striking veh.	Belts		27.2			
	Size of striking veh.	Belts	B-pillar	26.4	+1.5	-0.8	X
	"	"	Rural/urban	30.0	+5.1	+2.8	✓
	"	"	Speed limit	28.8	+3.9	+1.6	XX
	"	"	Occ. age	29.0	+4.1	+1.8	XX

✓ selected

X deleted: incremental change 1% or less

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7.6 A caveat - injury "reductions" in frontal crashes

The examination of side impact injury rates by model year (Section 7.4.5) did not reveal any obvious vehicle age-related biases. At the same time, due to sampling error fluctuations in the NCSS injury rates, it was impossible to reach a firm conclusion that such biases were nonexistent.

An alternative approach is to examine the injury rates in frontal crashes for pre- and post-Standard 214 cars. A substantial injury "reduction" for Standard 214 in frontal crashes could indicate bias in the frontal injury rates. Moreover, it would suggest that similar biases might be present in the side impact injury rates (although it cannot be proven that the bias would be the same in both impact types).

Table 7-17 shows the NCSS injury reductions in frontal single vehicle crashes. Cars of the first 2 model years with beams had a 21 percent lower injury rate than cars of the last 2 model years without them. There does not appear to be any satisfactory explanation for this rather large injury reduction, over a short time span, during a period in which hardly any frontal safety devices were introduced and belt usage did not increase. It could be an artifact of the NCSS file, since FARS did not show comparable reductions in frontal crashes (see Table 6-3).

Nevertheless, the 21 percent reduction in frontals is still much lower than the 55 percent effectiveness attributed to Standard 214 in side impacts by the multidimensional contingency table analysis of NCSS (Section 7.5.3). It would appear, then, that Standard 214 is effective in single

TABLE 7-17

INJURY REDUCTION IN FRONTAL SINGLE VEHICLE CRASHES,

POST VS. PRE STANDARD 214, NCSS

	First 2 MY with Beams vs. Last 2 MY w/o them	First 5 MY with Beams vs. Last 5 MY w/o them	All Cars with Beams vs. All Cars w/o them
Observed injury reduction in <u>frontal</u> crashes, NCSS (%)	21	23	21
<u>Frontal</u> injury reduction corrected for belt usage & FMVSS (%)	21	19	15
NCSS estimate of Std. 214 effectiveness in <u>side</u> impacts (from Section 7.5.3)	55	24	34

vehicle side impacts but that the 55 percent effectiveness estimate might be overstated - possibly on the order of 21 percent - due to a bias that could not be pinned down in the earlier analyses.

Table 7-17 shows that cars of the first 5 model years with beams had a 23 percent lower injury rate in frontal crashes than cars of the last 5 years without beams. Part of the injury reduction over this time span, however, is due to the introduction of frontal safety devices and an increase in belt usage - see Table 7-4. Belts and the other devices reduced the frontal injury rate by just over 4 percent (assuming frontal effectiveness for belts to be 60% [72], energy-absorbing steering columns 17% [44], and Standards 201 and 205, 8% each and based on the installation and usage rates in Table 7-4). As a result, the frontal injury reduction "attributed" to Standard 214 on NCSS is not 23 percent but only about 19 percent. This is still lower than the 24 percent effectiveness attributed to Standard 214 in side impacts in Section 7.5.3, but not too much lower.

The full set of cars with beams had a 21 percent lower NCSS injury rate in single vehicle frontals than the cars without beams. The portion of this reduction not attributed to other safety devices is about 15 percent. This is considerably lower than the 34 percent effectiveness attributed to Standard 214 in side impacts.

Thus, in all 3 cases, the reduction in side impacts is higher than the "reduction" in frontals and, in 2 out of 3 cases, it is considerably higher.

Table 7-18 shows the NCSS injury reductions in frontal multivehicle crashes. Cars of the first 2 model years with beams had a 5 percent lower injury rate than cars of the last 2 years without beams. This is a much smaller bias than in the single vehicle crashes. It is lower than the 11 percent effectiveness attributed to Standard 214 in side impacts (Section 7.5.4). But a possible 5 percent bias is not trivial when the effectiveness estimate is only 11 percent. The bias is, however, much lower than the 34 percent effectiveness attributed to Standard 214 for nearside occupants in compartment crashes (Section 7.5.5).

Cars of the first 5 years with beams had a 13 percent lower frontal injury rate than those of the last 5 years without beams. Correction for reductions attributable to belts and other safety devices leaves a possible bias of 9 percent. As in the 2 year comparison, this is about half as large as the effectiveness attributed to Standard 214 in side impacts (16%) and rather small compared to the effectiveness for nearside occupants in compartment impacts (25%).

The full set of cars with beams had an 11 percent lower frontal injury rate than the cars without beams, which after correction for other safety devices amounts to a bias of about 5 percent. Again, this is lower than the effectiveness estimate in side impacts (13%) and much lower than the estimate for nearside occupants in compartment impacts (30%).

In all 3 cases, the injury "reduction" in frontal multivehicle crashes is about half as large as the reduction in side impacts and quite small compared to the reduction for nearside occupants in compartment impacts.

TABLE 7-18

INJURY REDUCTION IN FRONTAL MULTIVEHICLE CRASHES,

POST VS. PRE STANDARD 214, NCSS

	First 2 MY with Beams vs. Last 2 MY w/o them	First 5 MY with Beams vs. Last MY w/o them	All Cars with Beams vs. All Cars w/o them
Observed injury reduction in frontal crashes, NCSS (%)	5	13	11
Frontal injury reduction corrected for belt usage & FMVSS (%)	5	9	5
NCSS estimate of Std 214 effectiveness in side impacts (%) (from Section 7.5.4)	11	16	13
NCSS estimate of Std. 214 effectiveness for nearside occupants in compartment impacts (%) (from Section 7.5.5)	34	25	30

7.7 Life-threatening injury reduction

All the analyses in the preceding sections defined an "injured" person as one who was hospitalized or killed. Only about a quarter to a third of hospitalizations involve injuries that are medically life-threatening. This section concentrates on life-threatening injuries. How does the effect of Standard 214 on them compare to its effect on other hospitalizations, on the one hand, and on fatalities (Chapter 6) on the other?

An occupant is defined to have life-threatening ("AIS $\geqslant$ 4") injury if that person was

- o killed, or
- o had at least one AIS $\geqslant$ 4 injury

Persons did <u>not</u> have life-threatening injury if

- o Their most severe injury was AIS 3 or less, or
- o the AIS were unknown, but they were neither killed nor hospitalized

About 2 percent of the NCSS cases fitted none of the above categories. They were considered unknowns and omitted from the analyses.

Table 7-19 presents the AIS $\geqslant$ 4 injury rates for 3 types of crashes (single veh., multiveh., multiveh. nearside/compartment) over 3 model year ranges ($\pm$ 2 years, $\pm$ 5, $\pm$ all years), each. They are based directly on tabulations from NCSS - no multidimensional contingency table

TABLE 7-19

AIS≥4 INJURY RATES IN SIDE IMPACTS

BY STANDARD 214 COMPLIANCE, NCSS

	Pre-Standard 214		Post-Standard 214		Reduction for
	N of Occ.	AIS≥4	N of Occ.	AIS≥4	Std. 214 (%)
IN SINGLE VEH. CRASHES					
2 years after vs. 2 yrs. before	473	28	519	14	54
5 years after vs. 5 yrs. before	990	54	1248	47	31
All post vs. all pre	1162	64	2041	72	36
IN MULTIVEH. CRASHES - ALL TYPES					
2 years after vs. 2 yrs. before	2756	43	3562	52	6
5 years after vs. 5 yrs. before	4895	89	8137	100	32
All post vs. all pre	6420	117	12147	159	28
NEARSIDE OCC. IN MULTIVEH. COMPARTMENT IMPACTS					
2 years after vs. 2 yrs. before	431	23	538	15	48
5 years after vs. 5 yrs. before	802	42	1278	36	46
All post vs. all pre	1206	50	1990	58	30

analyses are performed because the injury samples are too small. The AIS $\geqslant$ 4 reductions should be compared to the "preliminary" effectiveness estimates for hospitalization reduction in Tables 7-1, 7-2 and 7-3, which are also based on direct tabulation from NCSS.

For example, there were 473 persons in single vehicle side impacts of cars of the last 2 model years without beams; 28 had life-threatening injury. There were 519 persons in cars of the first 2 model years with beams; 14 had life-threatening injury. This is a 54 percent reduction in the AIS $\geqslant$ 4 injury rate. It is higher than the corresponding 47 percent hospitalization reduction (in Table 7-1).

In fact, the AIS $\geqslant$ 4 reductions are in <u>all</u> 9 cases <u>larger</u> than the corresponding hospitalization reductions. This is strong evidence that Standard 214 may be even more effective in preventing life-threatening injuries than against less severe injuries that require hospitalization. For example, the AIS $\geqslant$ 4 reductions in <u>single</u>-vehicle crashes are 54, 31 and 36 percent in the 2, 5 and all-year comparisons, respectively - strong evidence that Standard 214 caused an immediate reduction of life-threatening injury in these crashes.

It is not so clear that Standard 214 is effective in multivehicle crashes: the reduction in the 2 year comparison is only 6 percent. The reductions in the 5 and all-year comparisons, on the other hand, are much larger (32 and 28%)but could, to a large extent, reflect vehicle age-related biases.

For nearside occupants of cars struck in the compartment by another vehicle, however, there was an immediate 48 percent reduction of life-threatening injury in the 2 year comparison, which largely persisted in the 5 and all-year comparisons (46 and 30% reductions). For this restricted group of multivehicle crash-involved occupants, Standard 214 does appear to be effective.

The AIS $\geqslant 4$ reduction in NCSS appears to be higher than the fatality reduction on FARS, especially in multivehicle crashes: the fatality reduction on FARS is 23 percent in fixed-object crashes (see Section 10.7) and zero in multivehicle crashes (see Section 6.7). The reason is that a large percentage of the fatalities are head injuries (see Section 3.3.3 and [57]) which are only moderately affected by Standard 214 in single-vehicle crashes and hardly at all in multivehicle crashes (see Section 10.3). By contrast, nonfatal AIS$\geqslant 4$ injuries preponderantly occur in lower parts of the body and are significantly affected by Standard 214, especially in single-vehicle crashes and for nearside occupants in compartment impacts (see Section 10.3).

7.8 Summary: "Best" estimates of Standard 214 effectiveness

The main results of this chapter were 9 "refined" effectiveness estimates of Standard 214 based on multivariate analyses, 3 each for single vehicle side impacts, multivehicle side impacts and nearside occupants in multivehicle compartment impacts. The 9 estimates and their confidence bounds are displayed in Table 7-20. "Best" estimates of Standard 214 effectiveness are obtained for each of the 3 crash types (single, multi, multi nearside/compartment) by:

- comparing the statistical results for the 2, 5 and all model year ranges (Table 7-20)
- assessing the biases that could not be eliminated in the multivariate analysis (Section 7.4.4 and 7.4.5)
- looking at the "effects" of Standard 214 in frontal crashes (Section 7.6)
- comparing the NCSS results to FARS (Section 6.7 and 10.4)
- looking at the effects of Standard 214 on vehicle performance in crashes (Chapter 9) and on specific injury types (Chapter 10)

In single-vehicle crashes, the effectiveness estimates were 55 percent in the 2 year comparison, 24 percent in the 5 year comparison and 34 percent in the all-year comparison. This is strong evidence that Standard 214 caused an immediate injury reduction, which persisted over subsequent

TABLE 7-20

INJURY[1] REDUCTION ATTRIBUTED[2] TO

STANDARD 214 IN SIDE IMPACTS, NCSS

	First 2 MY with Beams vs. Last 2 MY w/o them	First 5 MY with Beams vs. Last 5 MY w/o them	All Cars with Beams vs. All Cars w/o them
SINGLE VEHICLE CRASHES			
Injury reduction (%)	55	24	34
Confidence bounds[3]	36 - 71	-3 - 40	20 - 44
MULTIVEHICLE CRASHES			
Injury reduction (%)	11	16	13
Confidence bounds	-3 - 24	7 - 24	2 - 22
NEARSIDE OCCUPANTS IN MULTIVEHICLE COMPARTMENT IMPACTS			
Injury reduction (%)	34	25	30
Confidence bounds	13 - 51	10 - 38	11 - 43

[1]A person is "injured" if killed or hospitalized

[2]Based on multidimensional contingency table analysis (Section 7.5)

[3]By jackknife procedure with one-sided α=.05

model years. No obvious biases in these estimates were found in the analysis of injury rates by model year; on the other hand, the comparison with frontal crashes (Section 7.6) suggested that these results, especially the 55 percent figure, could be overstated by as much as 20 percent. This suggests a "ceiling" on effectiveness in the 30-35 percent range. FARS showed an effectiveness of 14 percent in <u>all</u> types of single vehicle crashes (Section 6.7) but when that figure is made comparable to NCSS - by removing rollovers and collisions with trains - it rises to 23 percent (see 10.4). This could be considered a "floor" on the effectiveness, since all evidence suggests that Standard 214 would be more effective against nonfatal injuries (which include many pelvic and leg injuries) than fatalities (which are to a large extent head injuries).

Therefore, an effectiveness of <u>about 25 percent</u> serious injury reduction, more or less midway between the above "floor" and "ceiling" would seem reasonable to conclude for Standard 214 in <u>single</u> vehicle crashes. A value of this magnitude is also consistent with the results of Chapters 9 and 10, which show that Standard 214 changes damage patterns significantly - e.g., reducing the maximum depth of crush by about 20 percent - and was effective against many types of injuries, for both nearside and farside occupants, in single-vehicle crashes.

For <u>nearside occupants in multivehicle compartment crashes</u> - skipping, for a moment, the totality of multivehicle crashes - the 3 statistical estimates in Table 7-20 are in extremely close agreement: 34, 25 and 30 percent. Moreover, the highest estimate is in the 2 year comparison, in which vehicle age differences are minimized. The average of the 3 estimates is 30 percent. The comparison with frontal crashes (Section 7.6), however, suggests that each figure may be overstated by about 5 percent. This suggests that the best effectiveness estimate is about 25 percent. A value of this magnitude is consistent with the results of Chapter 10, which show that Standard 214 substantially reduces the leg, pelvic and (to a lesser extent) chest injuries of nearside occupants in contacts with the side of the passenger compartment in multivehicle compartment crashes - precisely the benefit that Standard 214 was intended to have - and little or no reduction of other multivehicle crash injuries. Since the above type of injury is rarely fatal, the fact that FARS showed no fatality reduction in multivehicle crashes is not inconsistent with a 25 percent reduction of nonfatal hospitalizations.

Finally, an effectiveness of about 8 percent seems reasonable for all types of multivehicle crashes, combined. Two arguments suggest this estimate:

(1) The effectiveness is about 25 percent for nearside occupants in compartment crashes. They account for one-third of the hospitalizations in multivehicle crashes (see Table 3-2). Since the results of Chapters 9 and 10 suggest that Standard 214 has negligible effect on farside occupants and in multivehicle impacts away from the compartment, the overall effectiveness in multivehicle should be about a third of the effectiveness for the nearside/compartment group.

(2) The 3 statistical estimates for overall effectiveness in multivehicle crashes are in extremely close agreement: 11, 16 and 13 percent - see Table 7-20. Their average is 13 percent. The comparison with frontal crashes suggests those estimates may be overstated by about 5 percent. Thus, the unbiased effectiveness estimate would appear to be 8 percent.

CHAPTER 8

NONSERIOUS INJURY REDUCTION FOR STANDARD 214: ANALYSES OF TEXAS DATA

The sampling scheme for the National Crash Severity Study results in the investigation of relatively small percentages of the nonserious injury and noninjury crashes that actually occurred. That makes NCSS unsuitable for statistically precise estimates of injury reduction when the injury criterion is something less serious than hospitalization. On the other hand, police agencies in Texas investigate over 400,000 traffic accidents each year. Because most of the agencies make use of the TAD system for classifying vehicle damage [82], it is easy to identify cars that were struck in the side. Injuries are classified as K (fatal), A ("serious visible injury"), B ("minor visible injury") or C("no visible injury - complaint of pain or momentary unconsciousness"). With appropriate analysis techniques, Texas data can be used to obtain precise estimates of the effectiveness of Standard 214 in reducing nonserious injury rates (any type of injury; K, A, or B injury). With less precision, the reduction of K or A level injury can be estimated. Although "K + A injury" and "hospitalization" are by no means identical criteria, there is enough overlap that K + A reduction may be considered a sort of check on the NCSS results on hospitalization.

The analyses of 1972, 74 and 77 Texas data described in this chapter show that Standard 214 significantly reduced nonserious injuries in multivehicle side impacts. There was also a significant reduction in K + A injuries, confirming the NCSS result that Standard 214 is effective in mitigating relatively serious nonfatal injuries in multivehicle crashes.

The Texas sample of single-vehicle side impacts contained only about a third as many injuries as the multivehicle sample. As a result, the observed injury reductions were not statistically significant, even though they were about the same as the reductions in the multivehicle crashes.

8.1 Analysis methods

The main problem in analyzing the effectiveness of a safety device by means of police-reported accident data is the vehicle age effect. The injury rate (the number of injured persons per 100 crash involved persons) escalates as cars get older - not only because the older cars lack safety devices but also, apparently, because noninjury crashes of older cars are less frequently reported. Since the post-Standard 214 cars are newer than the pre-standard cars, the injury rates will be lower, at least in part, due to the vehicle age effect.

Police data generally do not contain enough useful potential control variables to permit removal of the age effect by multivariate analyses such as were used on NCSS in Section 7.5. Besides, to the extent that the age effect is due to reporting biases, it cannot be removed by control variables, anyway (see Sections 7.1.4 and 7.4.5).

One approach to removing the vehicle age effect is to minimize the age difference between the pre and post-Standard 214 cars - i.e., use only cars of the last model year before beams were installed and the first model year with beams. The combined Texas accident files for 1972, 74 and 77 contain a large enough sample that, even with this severe restriction, statistically meaningful results are obtained. This is the approach used in Section 8.3. It was previously used, with the same years of Texas Data, in the evaluation of head restraints ([45], pp. 183-187). Also, in Section 6.3.1 of this report, FARS cases for the single model years before and after beam installation were successfully analyzed for an estimate of Standard 214 effectiveness.

Another approach is to remove the age effect analytically. Check the injury rates over a range of vehicle ages and find out if there is a trend. The effectiveness of Standard 214 is measured by the amount of deviation from the trend line in the year that side door beams were introduced. In other words, perform a log-linear regression on the injury rates as a function of Standard 214 compliance and vehicle age (plus certain other variables). This is the approach used in Section 8.4. Similar regressions were used in the evaluation of head restraints ([45], pp. 187-194) and in Section 6.6 of this report, on FARS-based fatality rates per 1000 car years. A regression is feasible because, with three nonadjacent years of Texas data and a wide range of initial years of beam installation, there are many Standard 214 cars on the files that are older than many pre-standard cars. In other words, vehicle age and Standard 214 compliance are largely uncorrelated independent variables.

8.2 Data preparation

Crash-involved drivers from the 1972, 74 and 77 Texas files were selected and prepared for analysis. Wherever possible, case selection and definitions were identical or analogous to those used in the analysis of FARS (see Chapter 6, especially Section 6.2). A detailed description of the Texas files may be found in the evaluation of head restraints [45], pp. 146-147 and 212-213. The following definitions were used:

(1) Only passenger cars from model years 1967-75 were selected on the first pass through the data, as in the FARS analyses of Chapter 6.

(2) Only drivers were selected. Texas police do not routinely indicate the presence of uninjured passengers so it is impossible to calculate passengers' injury rates. But they do keep a record of every driver, injured or uninjured.

(3) Side impacts were defined according to the TAD scheme and included codes LP, RP, LF, RF, LB, RB, LD, RD. In other words the definition includes right-side impacts (the far side relative to the driver) and damages that, according to police, were not necessarily centered on the compartment. Rollovers with side damage (LT and RT), however, were excluded.

(4) Crashes were classified as "single-vehicle" or "multi-vehicle" according to the number of motor vehicles in the accident.

(5) As in the FARS analysis, the objective was to obtain "comparable" samples of pre and post-standard cars and to pinpoint the initial year of beam installation. Where possible, makes and models were treated in the same manner as on FARS, e.g.,

- All imports except Volkswagen Beetles were deleted (uncertain beam installation year)
- 1970 Camaros and Firebirds, 1973 Volkswagen and most 1973 Chryslers were deleted (midyear installation)
- Vegas, Granadas, Corvairs, Sevilles, etc., were excluded (no comparable pre and post-standard cars)

(6) The year of initial beam installation was pinpointed, as on FARS, and models were grouped into 7 classes accordingly (1969, 70, 70.5, 71, 72, 73, 73.5).

(7) Dodge Charger required special treatment, as on FARS. Moreover, Buick Skylark, Mercury Comet and Pontiac Ventura were each two different cars during 1967-75 but represented by a single code in Texas. They had to be assigned to different "initial beam installation year" classes according to their model year.

8.3 Comparison of injury rates - first year with beams vs. last year without them

With the definitions of the preceding section, it is possible to select and tabulate all the drivers involved in side impact (during 1972, 74 or 77) in cars of the first full model year in which beams were installed - e.g., 1969 Impalas, 1970 Cutlasses, 1971 Camaros and Mustangs. It is likewise possible to tabulate drivers of comparable cars of the last full model year before beams were installed - e.g., 1968 Impalas, 1969 Cutlasses and Camaros, 1970 Mustangs.

Table 8-1 shows the drivers' injury rates in single vehicle side impacts. There were 5349 drivers of cars of the last model year without beams; 13.33 percent of them were injured. There were 4721 drivers in cars of the first year with beams; 12.86 percent of them were injured. This is a 4 percent reduction in the injury rate; the reduction is not statistically significant (confidence bounds -4 to 12, one-sided $\alpha = .05$).

Police are instructed to classify as level "C" those injuries that are not visible. The category probably consists, to a large extent, of noncontact pain injuries. (In rear impacts, where the most common injury is whiplash, the "C" category is far more frequent than in side

TABLE 8-1

DRIVER INJURY RATES IN SINGLE-VEHICLE

SIDE IMPACTS, FIRST YEAR WITH BEAMS

VS. LAST YEAR WITHOUT THEM, TEXAS 1972, 74 AND 77

	Last Model Year without beams	First Model Year with Beams	Observed Reduction for Std. 214 (%)	Confidence Bounds*
N of side impacts	5349	4721		
Percent of drivers injured	13.33	12.86	4	-4 to 12
Percent with K,A, or B injury	9.46	8.60	9	-1 to 19
Percent with K or A injury	2.41	2.12	12	-7 to 31

*One-sided α= .05

impacts - compare the table on p. 148 of [45] with Table 8-1.) These injuries are unlikely to be influenced by Standard 214. When the "C" injuries are excluded, the injury reduction for Standard 214 in single vehicle crashes rises to 9 percent and comes very close to significance (confidence bounds -1 to 19). Since "B" injuries are defined in Texas as "minor visible injuries," it seems possible that Standard 214 is effective in reducing nonserious injuries in single vehicle crashes.

When the injury criterion is further restricted to K or A, the observed reduction for Standard 214 again rises to 12 percent. Although this reduction is not statistically significant (confidence bounds -7 to 31 it is statistically compatible with the results from NCSS (25 percent hospitalization reduction) and FARS (14 percent fatality reduction).

The Texas files contain a much larger sample of multivehicle crashes than single-vehicle crashes. Table 8-2 compares driver injury rates in cars of the last model year without beams to those of the first year with beams. Although the injury reductions observed for Standard 214 are about the same as in single-vehicle crashes, they are all statistically significant, because of the larger sample size.

Standard 214 reduced the overall injury rate by a significant 5 percent (confidence bounds 1 to 9). When "C" injuries are eliminated, observed effectiveness rises substantially: the reduction of the K, A or B injury rate is 13 percent (confidence bounds 8 to 18), clearly indicating that Standard 214 is effective against nonserious injuries.

The reduction of K or A injuries is 18 percent (confidence bounds 8 to 28). This significant reduction is statistically compatible with and, in fact, slightly greater than the hospitalization reduction found in NCSS (8 percent - see Chapter 7). It confirms that Standard 214 is effective in reducing serious nonfatal injuries in multivehicle crashes.

8.4 Regression of injury rates

In the preceding analysis, the pre-standard cars were, on the average, one year older than the Standard 214 cars. Even a one-year difference might create a bias which, although small in absolute terms, is not negligible relative to the actual effectiveness of Standard 214 in reducing nonserious injuries.

Multiple regression of the side impact injury rates over model years 1967-75 permits removal of the vehicle age bias. In addition, the analysis

TABLE 8-2

DRIVER INJURY RATES IN MULTIVEHICLE SIDE IMPACTS, FIRST YEAR WITH BEAMS VS. LAST YEAR WITHOUT THEM, TEXAS 1972, 74 and 77

	Last Model Year without Beams	First Model Year with Beams	Observed Reduction for Std. 214 (%)	Confidence Bounds*
N of side impacts	42,904	40,545		
Percent of drivers injured	7.04	6.70	5	1 to 9
Percent with K, A or B injury	3.80	3.29	13	8 to 18
Percent with K or A injury	0.95	0.78	18	8 to 28

*One-sided α = .05

helps check whether the results of Section 8.3, which were based on a narrow range of model years, are consistent with results based on a broader sample.

The regression procedure is nearly identical to the one used with FARS data in Section 6.6. The makes and models are grouped into 7 classes, according to the model year in which beams were first installed. The injury rates (6 in all: KABC, KAB, KA for single and multivehicle crashes) are tabulated in each of these classes by model year (1967-75) and calendar year (1972, 74 or 77).

The dependent variable is the logarithm of the injury rate. The independent variables are

BEAMS = 1 if beam-equipped; 0 if not equipped

AGE = vehicle age = calendar year - model year

T70, T70.5, T71, T72, T73, T73.5 - indicating the model year in which transition to beams was made. For example T71 = 1 for cars which first obtained beams in 1971; 0 otherwise

CY72, CY77 indicating calendar year. For example CY77 = 1 for 1977 accidents; 0 otherwise

Over the 3 calendar years studied, AGE ranges from 0 - 10 for pre-standard cars and from 0 - 8 for post-standard cars. In other words, the ranges overlap greatly and AGE is not correlated with BEAMS in a manner that would invalidate the regression. The regression weight factor is

N_1 = number of single-vehicle crashes or

N_2 = number of multivehicle crashes

for the single-vehicle and multivehicle analyses, respectively.

These regressions did not produce meaningful results. It turns out that the injury rates for cars that got beams in later years (including a lot of small cars) are very significantly higher than those for cars that got beams early (mostly big cars). At the same time, the BEAMS variable is correlated with the T variables: over the full range of model years 1967-75, BEAMS = 1 for the vast majority of the cars of models that got beams in 1969 or 70 and BEAMS = 0 for the majority of cars of models that got them in 1973. Thus, there is a strong three-way interrelationship of BEAMS, T and the dependent variable. (This relationship was much weaker in the FARS analysis, where the dependent variable, fatalities per 1000 car years, was less correlated with T.) What the regression did was to take the (relatively weak) effect of BEAMS and lose it within the (strong) effect of the T variables. As a result, little or no effect was attributed to BEAMS or AGE. The differences in injury rates was accounted for mainly by the T variables.

The remedy for this problem was to eliminate the correlation of BEAMS with the T variables. It was accomplished by limiting the data to cars of the last 3 model years before or first 3 model years after beams were installed. For example, only 1967-72 Cutlasses and 1970-75 Pintos were used. As a result, there were more or less similar proportions of pre- vs. post-standard cars in each T group - i.e., little correlation of BEAMS with T.

The set of regressions run with the above data points produced more plausible coefficients for BEAMS and AGE. As in Section 6.6, the effectiveness of Standard 214 is estimated by $1 - e^b$, where b is the regression coefficient for BEAMS. The estimate is significantly different from zero if b, divided by its standard deviation, is in the critical region of a t distribution with the residual df of the regression.

Table 8-3 shows the effectiveness estimates generated by the regressions. The results should be compared to those in Tables 8-1 and 8-2 (based on simple comparison of injury rates one year before and after beam installation).

In single-vehicle crashes, the reductions in nonserious injuries attributed to Standard 214 were virtually nil: a 2 percent increase in all types of injuries and a 4 percent reduction of K, A or B injury. These results raise a question whether the modest reductions observed in Table 8-1 (4 and 9 percent, respectively) are really due to Standard 214. For K and A injuries, on the other hand, the regression (based on 3 model years) attributes a 16 percent reduction to Standard 214 which suggests that the estimate in Table 8-1 (12%, based on just one model year) may have been in error on the low side. Of course, the difference could be due to chance alone, since neither reduction was statistically significant.

Thus, for single-vehicle crashes, the regression results are consistent with the findings of Chapters 6 and 7 that Standard 214 reduces serious injuries. But the regressions show little or no effectiveness against minor injuries.

In multivehicle crashes, the effectiveness calculated by the regressions is just 1 - 4 percent lower than the results in Table 8-2. The

TABLE 8-3

INJURY REDUCTION FOR STANDARD 214

(By regression of side-impact injury rates in cars built within 3 years of the beam installation year, Texas 1972, 74 and 77)

	In Single-Vehicle Crashes	In Multivehicle Crashes
Reduction of injury - any type (%)	-2	2
Reduction of K, A or B injury (%)	4	9*
Reduction of K or A injury (%)	16	17

*Statistically significant reduction (one-sided $\alpha = .05$)

regressions attributed to Standard 214 a significant 9 percent reduction of K, A or B injury, a 17 percent reduction of K or A injury and a 2 percent overall injury reduction. Thus, they seem to confirm the earlier conclusion that Standard 214 is effective against nonserious injuries (of the "B" type) as well as serious nonfatal injuries.

In view of the methodological problems that were encountered in the regressions, it is recommended that their results be given lower weight than the simple year-after/year-before injury rate comparisons of Section 8.3.

CHAPTER 9

WHY IS STANDARD 214 EFFECTIVE?

ANALYSES OF NCSS DAMAGE DATA

Chapters 6, 7 and 8 presented statistical evidence that Standard 214 reduces casualties in side impact crashes but they did not explain <u>why</u> the reduction takes place. The "why" questions are addressed in Chapters 9 and 10. Standard 214 is a requirement that pertains mainly to vehicle structures. If it is effective, its effect should be discernable in the way it causes the structure to respond to impact forces -i.e., in the pattern of damage sustained by the vehicle. This Chapter compares damage data from the National Crash Severity Study (NCSS) for pre and post-Standard 214 cars, testing various hypotheses on why Standard 214 may have improved structural safety. (Chapter 10 examines the types of injuries mitigated by Standard 214 and the types of crashes where effectiveness is greatest.) Background information on the NCSS file may be found in Section 7.1.

The NCSS damage data indicate that Standard 214 has significantly modified structural performance in single vehicle crashes in a manner that should improve occupant protection. To a lesser extent, it has also modified performance in multivehicle crashes where the impact is centered on the passenger compartment.

9.1 <u>Five hypotheses on why Standard 214 might be effective</u>

In Section 4.3.1, five hypotheses on how Standard 214 might improve structural performance in side impacts were presented. In Chapter 4, the hypotheses were stated not as facts but as conjectures to be discussed in the light of engineering considerations and staged test results. Here, they are restated as a prelude to the analysis of damage patterns in highway accidents:

(1) Side door beams increase a door's crush resistance and reduce the velocity and distance that the door structure is driven into the passenger compartment in a side impact.

(2) Beams partially deflect a striking object or vehicle (when a longitudinal force component is present) and spread out the area of damage - thereby reducing the force levels and perhaps even the energy dissipated in a collision. Forces are better transmitted to the frame and pillars.

(3) The beam holds a striking vehicle down and forces it into the struck car's sill - a structure much more crush resistant than the door.

(4) In a fixed object collision, beams provide a hard structure parallel to and above the sill. They prevent the upper part of the car from being tipped over the sill into the striking object.

(5) Beams help preserve the structural integrity of the door and reduce stresses on door components - preventing door opening and associated occupant ejections.

9.2 How damage data are used to test the hypotheses

The most useful damage data on NCSS are the exterior crush measurements that are recorded as input to the CRASH computer program for estimating velocity changes during impacts [54]. They are the most useful because they are rarely unknown: missing on only 8 percent of NCSS side impacts. They are also relatively exact, being measured to the nearest inch.

NCSS also contains measurements of door intrusion into the passenger compartment but since these are missing in over 90 percent of the side impacts they are of little use for the type of analyses performed in this chapter.

The exterior crush measurements consist of the following

- o The width of the damaged area (L)
- o 4-6 depth measurements, equally spaced along the damaged area ($C_1,\ldots,C_6$)
- o The distance from the midpoint of the damaged area to the midpoint of the side of the car (D) - a positive number indicates that the midpoint of the damage is in the front half of the car.

Let C = max ($C_1,\ldots,C_6$) be the maximum depth of the exterior crush.

If the maximum crush C is lower for post-Standard 214 cars than pre-Standard cars it could mean that beams have somehow acted to reduce intrusion - or it could just be due to structural features other than beams or a reduction in crash severity for post-Standard cars. In Section 9.3, analytical procedures are developed (similar to those of Chapter 7) to filter out the effects of other structural features, etc. If, after the filtering, C is still significantly lower for Standard 214 cars, it can be concluded that beams have reduced intrusion, but why? Any combination of hypotheses 1-3 could be at work - an increase in door strength, a deflection of vehicles and objects, and/or a forcing of the striking vehicle into the strong sill.

If, however, the reduction in crush depth C is accompanied by an <u>increase</u> in the width L (or if C/L is reduced more sharply than C) it would be strong evidence for hypothesis (2). Wider, shallower damage patterns suggest that beams help deflect vehicles or objects and spread out the forces.

In <u>single vehicle</u> crashes (with fixed objects), there is nearly always engagement of the object with the cars' sill. Thus, hypothesis (3) - reduction of sill override - is irrelevant in single vehicle crashes. Furthermore, because the sill, not the door, absorbs the brunt of the impact, hypothesis (1) - direct increase in crush resistance due to a stronger door - is only of limited relevance. Therefore, a significant reduction of crush depth C, especially if it is accompanied by a significant increase of width L, is best explained by hypothesis (2) - deflection.

In multivehicle crashes, on the other hand, hypotheses (1) and (3) are potentially viable. If post-Standard cars have significantly lower crush depth C with no appreciable change in width L and if the depth reduction is found almost exclusively for impacts centered on the passenger compartment, it may be possible to discard hypthesis (2) - deflection - as a significant factor in Standard 214's benefits. The reduction in crush depth is likely due to increased door strength or reduced sill override. The relative importance of those two factors, however, cannot be readily gauged from crush depth data alone. The NCSS cases collected before April 1978 contain the additional damage data element needed for the analysis: presence or absence of sill override in multivehicle side impacts. These data are analyzed in Section 9.6, resulting in an assessment of the reduction in sill override attributable to Standard 214 and the relative importance of hypotheses (1) and (3).

Two other damage statistics supplement the analysis of crush depth and width and provide additional evidence for or against hypothesis (2). Based on the damaged width L and midpoint D it is possible to define which zones of the car were damaged (front fender, compartment and/or rear fender). If damage is less likely to be confined to the passenger compartment on post-standard cars and more likely to extend to the fenders, it would be additional evidence that Standard 214 helps deflect a striking object (or vehicle) and spreads out the damage (see Section 9.4). The principal direction of force (PDOF) is primarily a function of the vehicles' speeds and directions at impact. In actual accident investigations, however, it is reconstructed from the available evidence, often including vehicle damage. Shallow, spread out damage creates the appearance that crash forces were relatively oblique. Therefore, if post-standard 214 cars have significantly more oblique PDOF's than pre-standard cars, it could be additional evidence that beams aid in deflecting striking objects (see Section 9.5).

Hypothesis (4) - that beams help prevent a car from tipping over into an object - is tested by checking the distribution of the 3rd letter of the Collision Deformation Classification (vertical damage zones). A decrease in damages involving the "greenhouse" region of the car (above the belt line) could be indicative of the hypothesized effect - see Section 9.7.

Hypothesis (5) - that beams help maintain the structural integrity of doors - is tested in Section 9.8 by analyzing 3 data elements: the actual number of p[illegible] ejected through doors, the frequency with which a door was opened by the impact and the frequency of damage to door components (latches or hinges). The latter 2 data elements were recorded only on the pre-April 1978 NCSS cases.

9.3 Depth and width of the damaged area

The purpose of this section is to find what changes, if any, in the maximum absolute crush depth (C), the width of the damaged area (L) and the relative depth (C/L) occured in side impacts as a result of Standard 214.

9.3.1 Analysis technique

An initial approach to the analysis of the effect of Standard 214 on crush parameters might be to calculate the average values of C,L, and C/L for all pre-standard 214 cars on NCSS and compare them to the average for post-standard cars. This approach would have 3 shortcomings:

- An observed reduction in crush might not be entirely due to Standard 214. The pre-standard cars are older than the post-standard cars, so they might have had more severe crashes and, for that reason, they had more crush.

- Similarly, the reduction might be due to structural features (such as B-pillars, frames, etc.) other than those installed in response to Standard 214.

- The ordinary arithmetic average is not a good measure of central tendency of the distribution of crush. The average is unduly affected by the presence (or absense) on NCSS of a few freak accidents with extreme crush (i.e., the distribution of crush is skewed to the right)

As a remedy to the first shortcoming - biases due to vehicle age differences - each analysis will be performed for three ranges of vehicle age:

(1) Cars of the first <u>two</u> model years with beams vs. cars of the last two model years without them

(2) First <u>five</u> model years with beams vs. last five without them

(3) <u>All</u> cars with beams vs. all cars without them.

If the differences in damage patterns for pre and post-standard 214 cars are consistent across the 3 analyses, it would support a conjecture that the difference is due to Standard 214. If a difference appears only in the second or third comparison, it might be due more to vehicle age-related biases than Standard 214. This approach was used in the NCSS analyses of injury reduction (Chapter 7) and is described in detail in Section 7.2.

The second shortcoming - biases due to structural modifications other than Standard 214 - suggests a need for some sort of multivariate analysis: finding the effect of Standard 214 on crush while <u>controlling</u> for the effects of B-pillars, number of doors, etc. The dependent variables, C, L and C/L are all <u>continuous</u> variables, which raises a hope of using multiple regression, a much less complicated technique than the multi-dimensional contingency table analysis that was used with the injury rates in Section 7.5. The distributions of the raw values of the dependent variables, however, are too badly skewed to the right for meaningful regressions. First, the variables have to be transformed to normal variates. This is accomplished as follows:

Rank order all the values of C on the NCSS side impact file. For the ith observation on the NCSS file, let

$$C_i' = \text{PROBIT (rank } C_i/N)$$

where N is the total number of (unweighted) side-impacted vehicles on NCSS with known C and PROBIT is the inverse of the cumulative unit normal distribution. For example, since the 90th percentile of C is 25 inches, the value of C' corresponding to C=25 is C'=1.28, which is the 90th percentile of the unit normal distribution (see Table 9-1). L and C/L are similarly transformed to L' and (C/L)'.

The normal variates C', L' and (C/L)' are suitable dependent variables for multiple regression. Moreover, the averages of these variables, for any particular group of NCSS cases, are excellent measures of central tendency which can be readily transformed back to raw crush measurements by applying the inverse of the preceding transformation. For example, since the average value of C' in post-standard cars in single vehicle crashes is -.622 and since C'= -.622 corresponds to C = 7.5 inches, the maximum crush depth of post-standard cars in single-vehicle crashes "averages" 7.5 inches.

Table 9-1 shows selected percentiles of the distributions of C, L and C/L. It is easy to see that they are badly skewed to the right, especially C and C/L.

The transformation of the damage statistics to normal variates, needed for successful regression, also remedies the third shortcoming described above - it provides a statistically robust measure of central tendency, one that is not affected by a handful of extremely severe accidents.

The independent variables in the regression and their values are:

- o Standard 214 compliance (0 if no, 1 if yes, delete case if unknown)
- o Frame/unitized (1 if body and frame, 0 otherwise)
- o B pillar (0 if genuine hardtop, 1 if pillared, 0.5 if unknown)
- o N of doors (2 if two-door, 4 if four-door, 3 if unknown)
- o Rural/urban (1 if rural, 2 if urban)
- o Vehicle weight (in hundreds of pounds)

The derivation of the variables from NCSS is described in Sections 7.1.2, 7.5.2 and Appendix D. Each side-impacted vehicle on NCSS constitutes a case and each case is weighted by the inverse sampling fractions.

The regressions are performed for each of 3 dependent variables C', L' and (C/L)', for each of 3 age ranges (± 2 years, ±5 years, all cases) and for each of 4 crash types:

- o single vehicle crashes
- o single vehicle crashes with impact centered on the compartment
- o multivehicle crashes
- o multivehicle crashes with damage centered on the compartment

Damage is "centered" on the compartment if the midpoint of the damage D is between 15 inches behind and 45 inches in front of the midpoint of the car (see Section 7.1.1). Thus, a total of 36 regressions are performed.

The "average" value of C, for pre-standard cars, is the inverse

TABLE 9-1

PERCENTILES OF UNIT NORMAL DISTRIBUTION AND

OF CRUSH DEPTH (C), WIDTH OF DAMAGED AREA (L)

AND RELATIVE CRUSH DEPTH (C/L) IN SIDE IMPACTS,

UNWEIGHTED NCSS

Percentile	Unit Normal	Values C	L	C/L
1	-2.33	1.7 inches	9 inches	.017
5	-1.65	3.3	18	.043
10	-1.28	4.6	26	.064
20	-0.85	6.4	36	.095
30	-0.52	8.0	46	.125
40	-0.25	9.6	54.7	.154
50	0	11.3	63	.185
60	0.25	13.4	72	.233
70	0.52	15.9	81	.292
80	0.85	19.4	94	.385
90	1.28	25	116	.57
95	1.65	31	143	.84
99	2.33	44	202	1.8

transform of C' predicted by the regression when Standard 214 compliance is set to 0 and all other independent variables are set to their average value for pre and post-standard cars, combined. The "average" value of C for post-standard is the inverse transform of C' predicted when Standard 214 compliance is set to 1 and the other independent variables are set to the same values as above. Thus, also, for L and L/C.

Finally, a regression attributes a <u>significant</u> effect to Standard 214 if the regression coefficient for Standard 214 compliance, divided by its standard deviation, is within the critical range of a t distribution with residual df of the regression.

9.3.2 Damage in single-vehicle crashes

Table 9-2 clearly shows that Standard 214 made crash damage shallower in single vehicle crashes and spread it over a wider area. In cars of the last 2 model years before beams were installed, the deepest penetration (C) averaged 11 inches. In cars of the first 2 model years with beams, it was only 9 inches. This reduction persisted even after regression was used to control for other differences in the structural features of the two groups of cars. While crush depth was reduced by 2 inches, the width of the damaged area (L) <u>increased</u> by 10 inches, from 40 to 50. The relative crush depth, C/L, indicates how much damage patterns changed: in the pre-standard cars the depth of the damage was, on the average, 26 percent of the width; in post-standard cars, just 18 percent.

TABLE 9-2

EXTENT OF DAMAGE IN SINGLE-VEHICLE SIDE IMPACTS, BY STANDARD 214 COMPLIANCE, NCSS

	Average Damage			
	Without Regression		With Regression**	
	Pre 214	Post 214	Pre 214	Post 214
First 2 MY with beams vs. last 2 MY w/o them				
Maximum crush depth-inches (C)	11	9	11	9
Width of damage-inches (L)	40	50	40	50*
Relative depth (C/L)	.28	.17	.26	.18*
First 5 MY with beams vs. last 5 MY w/o them				
Maximum crush depth-inches (C)	10	7	10	7*
Width of damage-inches (L)	44	53	44	53*
Relative depth (C/L)	.24	.14	.23	.15*
All cars with beams vs. all cars without them				
Maximum crush depth-inches (C)	10	8	10	8*
Width of damage-inches (L)	43	51	45	50
Relative depth (C/L)	.24	.16	.23	.16*

*Regression attributes significant change to Standard 214

**Controlling for frame/unitized, B-pillar, N of doors, rural/urban and vehicle weight

The above changes are based only on cars of the 2 model years before and after beam installation. Extending the data set to include additional model years gave nearly identical results. For example, when cars of the first 5 years with beams were compared to the last 5 years without them, crush depth was reduced by 3 inches while width increased by 9 inches. The average value of C/L dropped from 23 percent to 15 percent. When the data set was further extended to include all model years, the regressions model again attributed nearly the same changes to Standard 214.

The invariance of the results across pre-standard model years and a similar invariance across post-standard model years, together with the abrupt change that took place at the time when beams were installed, is evidence that the change in damage patterns is an effect of Standard 214 and not the result of a long-term vehicle age-related trend toward more oblique impacts.

In 7 of the 9 regressions, the effect attributed to Standard 214 was statistically significant.

The longer, shallower damage patterns are evidence that Standard 214 helps a vehicle partially deflect or scrape by a fixed object. What are the implications for the occupants' safety? The numbers in Table 9-2 provide some ideas.

Since the damaged area has become longer, the post-standard car has, on the average, a longer duration of contact with the fixed object than the pre-standard car. At the same time, the depth of crush - and the amount of door intrusion - has decreased. If the door is pushed in a shorter distance over a longer time period, the velocity of door intrusion into the compartment will be decreased twofold - and velocity of door intrusion is widely thought to be a critical factor in determining the severity of chest, pelvis and leg injuries of the occupant seated adjacent to the door.

But the benefits are not necessarily limited to the nearside occupant. As stated above, the duration of contact with the fixed object is longer. Even if the overall velocity change (or energy dissipation) were the same for pre and post-standard cars, the deceleration would be smaller for the latter, since the velocity change takes place over a longer time. The reduction in deceleration is beneficial to all occupants.

Moreover, the velocity change is not necessarily the same for pre and post-standard cars. Intuitively, the post-standard car "scrapes by" a fixed object and may keep on moving, in the same direction, at a higher speed than the pre-standard car which "hangs up" on the object - i.e., the velocity change is less. The numbers in Table 9-2 confirm this effect. The amount of energy dissipated in the collision (assuming the fixed object is rigid and dissipates no energy) should be roughly proportional to C^2L, since a car resembles an inelastic spring with regard to crush resistance. (It is also assumed that in a fixed object collision, where much of the energy is absorbed in the sill, beams do not substantially increase overall crush resistance.) Based on the average values of C and L in Table 9-2, C^2 L is 20-30 percent lower for post-standard cars.

Thus it is possible that Standard 214 has reduced a car's velocity change in single vehicle side impacts. Since, as noted above, the velocity change takes place over a longer contact period, there would be a twofold reduction of acceleration. The reduction in a car's overall Delta V and g's should benefit all occupants and might reduce the risk of many kinds of injuries - including head lesions and injuries due to contacts other than the car's side surfaces.

Table 9-3 shows the effect of Standard 214 on damage patterns in single vehicle crashes where the damage was centered on the occupant compartment. An important caveat for this table is that the pre and post-standard cases are not directly comparable because Standard 214 tends to spread damage to the rear fender areas and move the midpoint of the damage out of the compartment area (see Section 9.4). Thus the post-standard cars in Table 9-3 may have been involved in more severe crashes than the pre-standard cars.

The purpose of Table 9-3 is to check whether the effect of Standard 214 is limited to crashes with damage centered on the compartment. Almost half of the side impacts are centered on the compartment (see Table 9-6). Thus, if the effects in Table 9-3 were generally double the effects in Table 9-2 (all single vehicle side impacts) it would imply that Standard 214 had negligible effect on damage in crashes not centered on the compartment.

TABLE 9-3

EXTENT OF DAMAGE IN SINGLE-VEHICLE SIDE IMPACTS CENTERED ON THE OCCUPANT COMPARTMENT, BY STANDARD 214 COMPLIANCE, NCSS

	Average Damage			
	Without Regression		With Regression**	
	Pre 214	Post 214	Pre 214	Post 214
First 2 MY with beams vs. last 2 MY w/o them				
Maximum crush depth-inches (C)	12	10	11	11
Width of damage-inches (L)	41	66	46	61*
Relative depth (C/L)	.29	.17	.25	.19
First 5 MY with beams vs. last 5 MY w/o them				
Maximum crush depth-inches (C)	11	9	11	9*
Width of damage-inches (L)	47	67	46	68*
Relative depth (C/L)	.25	.16	.25	.15*
All cars with beams vs. all cars without them				
Maximum crush depth-inches (C)	10	8	11	8*
Width of damage-inches (L)	48	66	49	65*
Relative depth (C/L)	.23	.15	.24	.15*

*Regression attributes significant change to Standard 214

**Controlling for frame/unitized, B-pillar, N of doors, rural/urban and vehicle weight

In fact, the effects in Table 9-3 are only a little bit larger than those in Table 9-2. For example, in impacts centered on the passenger compartment, C/L is, on the average, 9 or 10 percentage points lower in post-standard than in pre-standard cars. In all side impacts (Table 9-2), it is 7 or 8 percentage points lower. Standard 214 reduced crush depth by about 2 inches in compartment impacts, which is the same as in Table 9-2. It increased the width of damage by about 15 inches, which is 50 percent more than in Table 9-2. The effect in compartment impacts was not twice as large as the effect in all types of crashes. It is concluded (subject to the caveat mentioned above) that the benefits of Standard 214 in single vehicle crashes are <u>not limited</u> to crashes centered on the compartment. The standard appears to be partially effective in deflecting objects in impacts whose damage envelope has less than 50 percent overlap with the compartment. It is even possible (although unproven by the analyses shown here) that the standard has some benefit in impacts with little or no compartment overlap: the beam may act as a box girder which adds to the longitudinal strength of a vehicle and, in an oblique front fender impact, may help the fender deflect an object.

The damage patterns in single vehicle crashes are consistent with the findings of Chapters 6, 7 and 10, viz., that the casualty-reducing benefits of Standard 214 in single vehicle crashes are not limited to near-side occupants, nor to injuries involving contact with the adjacent vehicle side structure, nor to crashes with damage centered on the occupant compartment.

9.3.3 Damage in multivehicle crashes

Table 9-4 clearly shows that Standard 214 reduced the depth of crush in multivehicle crashes. Pre-standard cars had an average of 10 inches crush, regardless of what model years were included in the comparison. Post-standard cars had an average of 9 inches crush, in all model year groups. The reduction of crush depth was statistically significant in each regression: the 2 year, 5 year and all-year comparisons.

It is unclear from Table 9-4, however, whether Standard 214 had any effect on the width of the damaged area. In the 2 year comparison, average width increased by 4 inches, from 56 to 60 inches, a statistically significant difference (although considerably smaller than the 10 inch increase in single vehicle crashes). The effect, however, does not persist over wider ranges of model years. In the 5 year comparison, L increased by 2 inches for post-standard cars; in the all-year comparison, by only 1 inch; neither of them are statistically significant changes. Moreover, the average value of C/L decreased in all 3 comparisons from .18 to .16, which is proportionately the same as the reduction C from 10 to 9 inches.

Table 9-5, which is limited to multivehicle impacts centered on the passenger compartment, clarifies the effects of Standard 214. There, in the 5-year and all-year comparisons, L is exactly the same before and after Standard 214. In the 2 year comparison, L is actually 2 inches lower for the post-standard cars (not a statistically significant change). Based on the evidence in Tables 9-4 and 9-5, combined, it may be concluded that Standard 214 had little or no effect on the width of the damaged area in multivehicle crashes (The conclusion will be further supported by the data in Sections 9.4 and 9.5). Thus, Standard 214 does not appear to be effective

TABLE 9-4

EXTENT OF DAMAGE IN MULTIVEHICLE SIDE IMPACTS,

BY STANDARD 214 COMPLIANCE, NCSS

	Average Damage			
	Without Regression		With Regression**	
	Pre 214	Post 214	Pre 214	Post 214
First 2 MY with beams vs. last 2 MY w/o them				
Maximum crush depth-inches (C)	10	9	10	9*
Width of damage-inches (L)	55	61	56	60*
Relative depth (C/L)	.19	.15	.18	.16*
First 5 MY with beams vs. last 5 MY w/o them				
Maximum crush depth-inches (C)	10	9	10	9*
Width of damage-inches (L)	56	59	56	58
Relative depth (C/L)	.18	.16	.18	.16*
All cars with beams vs. all cars without them				
Maximum crush depth-inches (C)	10	9	10	9*
Width of damage-inches (L)	56	59	57	58
Relative depth (C/L)	.18	.16	.18	.16*

*Regression attributes significant change to Standard 214

**Controlling for frame/unitized, B-pillar, N of doors, rural/urban and vehicle weight

in partially deflecting a striking vehicle.

Table 9-5 clearly shows that Standard 214 reduced the average crush depth by 2 inches in crashes centered on the compartment - in all 3 comparisons, the reduction was 2 inches and it was statistically significant. The reduction of C in compartment crashes is exactly double the overall reduction shown in Table 9-4. Since about one third of the crashes are centered on the compartment (see Table 9-7) it may be concluded that Standard 214 reduced crush depth in the other crashes by only a half inch, - i.e., $\frac{1}{3} \times 2'' + \frac{2}{3} \times \frac{1}{2}'' = 1$ inch overall average reduction.

Thus, the effect of Standard 214 in multivehicle crashes is limited to reducing the depth of crush and that, primarily, in compartment crashes. What are the implications for occupant safety? A reduction of crush - and door intrusion - in compartment crashes, with all other factors equal, should result in a reduction of the velocity with which the intruding door and the adjacent occupant contact one another. The nearside occupant's chest, pelvic and leg injuries due to contact with the side interior surface should be decreased in severity - in compartment crashes.

Since the overall duration of the impact, the amount of energy absorbed, etc., are not significantly affected, it is unreasonable to expect significant benefits for farside occupants or for injuries not involving contact with side surfaces, especially head injuries. Also, significant benefits should not be expected in crashes not centered on the compartment.

TABLE 9-5

EXTENT OF DAMAGE IN MULTIVEHICLE SIDE IMPACTS CENTERED ON THE OCCUPANT COMPARTMENT, BY STANDARD 214 COMPLIANCE, NCSS

	Average Damage			
	Without Regression		With Regression**	
	Pre 214	Post 214	Pre 214	Post 214
First 2 MY with beams vs. last 2 MY w/o them				
Maximum crush depth-inches (C)	11	9	11	9*
Width of damage-inches (L)	75	73	75	73
Relative depth (C/L)	.14	.13	.15	.13
First 5 MY with beams vs. last 5 MY w/o them				
Maximum crush depth-inches (C)	10	8	10	8*
Width of damage-inches (L)	54	54	54	54
Relative depth (C/L)	.15	.13	.15	.13*
All cars with beams vs. all cars without them				
Maximum crush depth-inches (C)	10	8	10	8*
Width of damage-inches (L)	53	54	53	53
Relative depth (C/L)	.15	.12	.15	.12*

*Regression attributes significant change to Standard 214

**Controlling for frame/unitized, B-pillar, N of doors, rural/urban and vehicle weight

These are precisely the findings of the injury-reduction analyses of Chapters 6, 7 and 10.

It remains to be determined <u>why</u> Standard 214 reduced crush depth in compartment crashes. Is it more a direct consequence of the crush resistance added by beams (hypothesis 1) or does it occur mainly because beams help prevent sill override (hypothesis 3)? The question is analyzed in Section 9.6.

9.4 Occupant compartment versus fender damage

Table 9-6 shows which zones of the car were damaged in <u>single vehicle</u> side impacts. The car has been divided into 2 zones: the "occupant compartment," which is defined to extend from 45 inches in front of the midpoint of the car to 15 inches behind it; and the "fenders," which comprise the remainder of the car. Note that this definition does not correspond precisely to the actual door and fender regions of individual cars, but it does have the advantage of being consistent across the vehicle fleet. (The specific dimensions of the "compartment" zone are based on measurements of actual cars and fully encompass the front door area of a large 2 door car.)

Based on the 2 damage zones, 3 types of damage are distinguished in Table 9-6:

- o Damage confined to the fender zone
- o Some compartment damage, but midpoint of the damage is in the fender zone
- o Damage centered on the compartment

TABLE 9-6

OCCUPANT COMPARTMENT VS FENDER DAMAGE IN SINGLE-VEHICLE SIDE IMPACTS, BY STANDARD 214 COMPLIANCE

Vehicle Age Range	Percent of Damaged Vehicles with Fender Damage Only	Some Compartment Damage: Centered on Fenders	Some Compartment Damage: Centered on Compartment
Last 2 MY w/o beams	6	31	63
First 2 MY w beams	34	26	40
Last 5 MY w/o beams	26	24	50
First 5 MY w beams	34	28	38
All cars without beams	28	24	48
All cars with beams	35	26	39

Table 9-6 shows that Standard 214 clearly reduced the incidence of damage concentrated on the compartment. Whereas 63 percent of the crash-involved cars of the last 2 model years without beams had damage centered on the compartment, only 40 percent of cars of the first 2 model years with beams did so. This effect persisted (although to a lesser extent) when the sample was extended to include additional model years: in the 5 year comparison, Standard 214 reduced compartment-centered damage from 50 to 38 percent of the vehicles; in the full NCSS, from 48 to 39 percent.

The reduction in compartment centered damage is apparently offset by gains in <u>both</u> of the other damage categories. The percent of cars with only fender damage increased substantially in all 3 comparisons. The percent of cars with some compartment damage, but centered on the fenders, increased in the two comparisons which involved relatively large samples (i.e., the 5-year and all-year comparisons).

The observed data are consistent with the following explanations:

(a) When the impact with a fixed object is mainly directed at the compartment, Standard 214 helps deflect the object and spread out the damage to the fender areas, possibly moving the center of the damaged area to a point outside the compartment.

(b) When the impact with a fixed object is mainly directed at the fender, Standard 214 may help <u>prevent</u> the damage from spreading to the door area - by increasing the longitudinal strength of the door structure and halting the damage before the A pillar.

(c) Standard 214 reduces the need for towing in impacts aimed at the compartment - thus, the reduction of these crashes relative to others on NCSS is an artifact due to NCSS being a towaway file (see Section 7.4.7).

Explanations (a) and (b), if valid, would have benefits for occupant safety. Explanation (a) is merely a restatement of hypothesis (2) of Section 9.1 - that beams help deflect objects - and a reaffirmation of the findings on the width of the damaged area (Section 9.3.2). Explanation (b) indicates an additional benefit of Standard 214 that was not evident from the analysis of crush width and depth and an additional reason why the benefits of Standard 214 in single vehicle crashes are not necessarily limited to impacts directly aimed at the compartment.

Explanation (c), if valid, would indicate that the results in Table 9-6 are biased and not necessarily indicative of benefits for Standard 214. The analyses of Section 7.4.7, in which the towaway involvement rates in side and frontal impacts are compared, do not suggest that Standard 214 has substantially reduced the need for towing in single-vehicle side impacts, so they do not support explanation (c).

Table 9-7 shows the zones of the car that were damaged in multivehicle crashes. In all 3 comparisons, the damage distribution for pre- and post-standard cars are virtually identical and certainly do not indicate a shift of damage from the compartment to the fenders. This

TABLE 9-7

OCCUPANT COMPARTMENT VS. FENDER DAMAGE IN MULTIVEHICLE SIDE IMPACTS, BY STANDARD 214 COMPLIANCE

Vehicle Age Range	Percent of Damaged Vehicles with		
	Fender Damage Only	Some Compartment Damage	
		Centered on Fenders	Centered on Compartment
Last 2 MY w/o beams	37	32	31
First 2 MY w. beams	33	36	31
Last 5 MY w/o beams	36	33	31
First 5 MY w. beams	34	34	32
All cars without beams	37	32	31
All cars with beams	33	33	34

confirms the conclusion of the analysis of crush depth and width (Section 9.3.3), viz., that Standard 214 is not effective in deflecting a striking vehicle.

9.5 Principal direction of force

NCSS investigators must reconstruct the accident based on the evidence that remains after the fact. One of their tasks is to estimate the principal direction of force (PDOF) experienced by each vehicle. A car's damage is one of the most important pieces of evidence indicating the direction from which the car was struck. In a side impact, wide shallow damage could be interpreted to indicate an oblique direction of force while concentrated damage has the appearance of perpendicular force. If post-Standard 214 cars on NCSS have significantly different PDOF distributions than pre-standard cars, it could be a result of the way damage patterns are interpreted by the investigators, rather than an actual change in vehicle alignments at impact. A shift toward more oblique estimates of PDOF, then, could be additional evidence that Standard 214 is effective in deflecting objects or vehicles and spreading out the damage - hypothesis (2).

The PDOF's on NCSS are estimated to the nearest 30 degrees, using the scheme of a clock, with 12:00 representing purely frontal force [12]. The objective of the present analysis, however, is only to measure whether PDOF is perpendicular or oblique - without distinguishing right from left or front from rear. Thus, the o'clock PDOF's are transformed to an angle of 0, 30, 60 or 90 degrees as follows:

- o perpendicular PDOF's of 3:00 or 9:00 are transformed to 90°
- o axial PDOF's of 12:00 or 6:00 to 0°
- o 2:00, 4:00, 8:00 and 10:00 to 60°
- o 1:00, 5:00, 7:00 and 11:00 to 30°

Next, the angle value of PDOF, as defined above, is used as the dependent variable in regressions similar to those performed in Section 9.3 - i.e., with Standard 214 compliance and other structural features as the independent variables.

Table 9-8 shows the regression results for single-vehicle crashes. Obviously, Standard 214 caused an immediate and significant shift toward more "oblique" crashes on NCSS. For example, cars of the last 2 model years before beams were installed had an average PDOF of 63 degrees from axial. Cars of the first 2 model years with beams had an average PDOF of 54 degrees from axial. This is a significant shift of 9 degrees towards more oblique crashes. There were virtually identical shifts in the 5-year and all-year comparisons. Table 9-8 shows no long-term trend in PDOF whatsoever, except for the abrupt change when beams were installed. It must be concluded that the change in estimated PDOF's is not a result of changes in the direction of vehicle motion immediately prior to impact, but an effect of Standard 214 - most likely, that the shallower damage patterns due to Standard 214 gave the appearance that a more oblique crash had taken place.

TABLE 9-8

PRINCIPAL DIRECTION OF FORCE, AS RECORDED BY NCSS INVESTIGATORS, IN SINGLE-VEHICLE SIDE IMPACTS, BY STANDARD 214 COMPLIANCE

Vehicle Age Range	All Single-Vehicle Crashes		Compartment-Centered Crashes	
	Average PDOF**	Change for Std. 214	Average PDOF**	Change for Std. 214
Last 2 MY w/o beams	63°	-9*	63°	-17*
First 2 MY w. beams	54°		46°	
Last 5 MY w/o beams	58°	-9*	61°	-11*
First 5 MY w. beams	49°		50°	
All cars without beams	58°	-8*	58°	-11*
All cars with beams	50°		47°	

*Regression attributes significant change to Standard 214

**90° = perpendicular to struck vehicle
0° = parallel to struck vehicle
Based on regression, with frame/unitized, B pillar, N of doors, rural/urban and vehicle weight as control variables

Table 9-8 also shows that the effect of Standard 214 in single vehicle crashes centered on the compartment were especially strong, with PDOF changes of 11-17 degrees, as compared to 8-9 degrees overall.

The changes in PDOF in single-vehicle crashes are consistent with the changes in crush depth and width and provide additional confirmation of hypothesis (2) - that Standard 214 helps a car deflect or scrape by a fixed object.

By contrast, Table 9-9 shows that Standard 214 has little or no effect on PDOF in <u>multivehicle</u> crashes. The 2 and 5 year comparisons both indicate a nonsignificant 1 degree shift toward more oblique PDOF (as compared to the significant 9 degree shift in the single-vehicle crashes). The all-year comparison shows a 2 degree shift which is significant, although small in absolute terms. This shift may be due to vehicle age-related changes in the distribution of crash alignments rather than Standard 214, since it is not confirmed by the 2 and 5 year comparisons.

The results for multivehicle crashes centered on the occupant compartment are no different. Specifically, no change in PDOF was found in in the 2 year comparison.

In multivehicle crashes, too, the results on PDOF are consistent with the findings on crush depth and width: they support a conclusion that Standard 214 does little or nothing to help a car deflect a striking vehicle.

9.6 <u>Sill override in multivehicle crashes</u>

In a multivehicle crash, the striking vehicle is said to "override the sill" if its frontal structure contacts the door but fails to engage the

TABLE 9-9

PRINCIPAL DIRECTION OF FORCE, AS RECORDED BY NCSS INVESTIGATORS, IN MULTIVEHICLE SIDE IMPACTS, BY STANDARD 214 COMPLIANCE

Vehicle Age Range	All Multivehicle Crashes		Compartment-Centered Crashes	
	Average PDOF**	Change for Std. 214	Average PDOF**	Change for Std. 214
Last 2 MY w/o beams First 2 MY w. beams	55^{o} 54^{o}	-1	55^{o} 55^{o}	none
Last 5 MY w/o beams First 5 MY w. beams	56^{o} 55^{o}	-1	55^{o} 53^{o}	-2
All cars without beams All cars with beams	56^{o} 54^{o}	-2*	54^{o} 51^{o}	-3*

*Regression attributes <u>significant</u> change to Standard 214

**90^{o} = perpendicular to struck vehicle
0^{o} = parallel to struck vehicle
Based on regression, with frame/unitized, B pillar, N of doors, rural/urban and vehicle weight as control variables

sill in a significant way. Sill override is widely mentioned as a contributing factor to intrusion and nearside occupant injury (see Section 3.2.2). Hedeen reported that tests of the GM side door beam showed that it forced the striking vehicle downwards and enhanced contact with the sill [39]. If the same phenomenon occurred in highway accidents, it would be a significant factor in why Standard 214 reduces injuries of near-side occupants in multivehicle compartment impacts - hypothesis (3) in Section 9.1.

The presence (or absence) of sill override was recorded in NCSS cases prior to April 1978 (about 55 percent of the NCSS file). Table 9-10 shows the incidence of sill override in the unweighted NCSS cases (unweighted cases are used for this analysis because the results are much more statistically reliable, despite some bias). Cars of the first 2 model years with beams had a 41 percent lower incidence of sill override than cars of the last 2 years with beams. The reduction is statistically significant. This very large reduction did not persist when the sample was extended to cover a wider range of model years. In the 5 year comparison, the post-standard cars had 25 percent fewer sill overrides. Nevertheless, this is still a significant reduction. In the all-year comparison, the reduction dropped to 18 percent, which was not significant but came extremely close to significance ($z = 1.63$).

Based on the evidence in Table 9-10, it is not certain that Standard 214 reduced sill override, but it is very likely. Based on the 2, 5 and all year comparisons, it would appear likely that Standard 214 may have reduced sill override by about 20 percent.

What are the implications for occupant safety? To gauge the benefits of a 20 percent reduction in sill override, it is necessary to know

- what percentage of all multivehicle side impacts involved sill override
- what are the benefits (in terms of reduced crush depth) of preventing sill override

The 585 unweighted NCSS cases and 103 sill overrides of pre-Standard 214 cars (next to last line of Table 9-10), when weighted by their inverse sampling fractions, correspond to 2541 vehicles and 337 sill overrides. Thus, 13 percent of the pre-standard cars had sill override.

The amount of intrusion avoided by engaging the sill may be estimated from crash test results: Hollowell and Pavlick reported that intrusion was reduced by 5 inches (from 16 to 11) as a result of lowering the striking car's bumper to force sill engagement [41]. Kitamura, Watanabe and Matsushita reported similar findings (see [48] and Section 4.4.4). The crash tests in these studies were about as severe as the average NCSS collision.

In other words, Standard 214 may reduce the likelihood of sill override by 20 percent. It has been occurring in 13 percent of side impacts. When it occurred, it increased crush depth by 5 inches. Thus the net benefit per car of Standard 214 is

average crush reduction = .20 x .13 x 5 inches = 0.13 inch

TABLE 9-10

SILL OVERRIDE IN MULTIVEHICLE SIDE IMPACTS, BY STANDARD 214 COMPLIANCE, UNWEIGHTED NCSS, PRE-APRIL 1978

Vehicle Age Range	Unweighted n of Cars	Car with Sill Override	Reduction for Standard 214 (%)
Last 2 MY w/o beams	242	51	41*
First 2 MY w. beams	282	35	
Last 5 MY w/o beams	424	85	25*
First 5 MY w. beams	651	98	
All cars without beams	585	103	18
All cars with beams	966	140	

*significant reduction for Standard 214 ($\alpha = .05$)

Now, in Table 9-4, it was shown that the overall crush depth reduction attributable to Standard 214 in multivehicle crashes was 1 inch. The results of this Section are that the crush depth reduction due to sill override prevention may be 0.13 inch. This is only a small fraction of the overall reduction. A much larger portion (viz., 0.87 inches) should be attributed to other causes - i.e., a direct increase of doors' crush resistance.

The results of this section suggest that hypotheses (1) and (3) are both true for multivehicle crashes, but hypothesis (1) is much more important. These results are consistent with the findings of Chapters 6, 7 and 10, i.e., that the effectiveness of Standard 214 in multivehicle crashes is limited to nonfatal injuries, due to contact with side structures, for nearside occupants in compartment impacts. Specifically, they are consistent with the finding that fatalities were not reduced: it appears that the primary reason for Standard 214 effectiveness in multivehicle crashes is hypothesis (1) - beams directly improve crush resistance. The improvement is probably quite limited in really severe crashes of the type likely to result in fatalities. Moreover, as noted in Section 7.8 and 10.2.3, the type of multivehicle crash injuries that Standard 214 is most effective in preventing is rarely fatal.

9.7 Damage above the beltline in single-vehicle crashes

A large proportion of single vehicle side impacts involve fixed objects that are more or less perpendicular to the ground and extend from the ground up beyond the roof of the car (e.g., poles, trees, walls). In a pre-Standard 214 car, the sill is strong while the upper portions of the car are relatively soft. In an impact with a fixed object, the sill would be brought to a stop while the soft upper portions of the car would keep moving, causing the car to tilt sideways (comparable to the pitching effect seen during emergency braking). This motion could aggravate penetration by the fixed object into the uppermost portion of the car and increase injury risk. It is conceivable that side door beams, which strengthen the upper portion of the car, parallel to the sill, could at least partially reduce the effect (hypothesis (4) in Section 9.1).

The presence (or absence) of damage to the portion of the car above the beltline, also known as the "greenhouse," is indicated on NCSS by the 3rd letter of the CDC: specific vertical area of damage [12]. If the 3rd letter is A, G or H, the greenhouse was damaged in the crash. Table 9-11 shows the incidence of greenhouse damage in the unweighted NCSS cases (unweighted cases are used for this analysis because the results are more statistically reliable, despite some bias).

No statistically significant reductions of greenhouse damage were found. In fact, cars of the first 2 model years with beams had the same incidence of greenhouse damage as cars of the last 2 model years without beams. On the other hand, greenhouse damage decreased by a nonsignificant 13 percent in the 5 year comparison and 14 percent in the all-year comparison. It is doubtful whether these observed effects can be considered supporting evidence for hypothesis (4). Other possible explanations are: chance alone (since the effects are not statistically significant); structural changes other than Standard 214, especially the large-scale introduction of pillared

TABLE 9-11

DAMAGE ABOVE THE BELTLINE IN SINGLE-VEHICLE SIDE IMPACTS, BY STANDARD 214 COMPLIANCE, UNWEIGHTED NCSS

Vehicle Age Range	Unweighted n of Cars	Cars with Greenhouse Damage*	Reduction for Standard 214 (%)
Last 2 MY w/o beams	93	46	none
First 2 MY w. beams	75	37	
Last 5 MY w/o beams	172	89	13
First 5 MY w. beams	195	88	
All cars without beams	217	113	14
All cars with beams	320	144	

*3rd letter of Collision Deformation Classification is A, G or H hardtops which took place 3-5 years after beams were installed; the tendency of Standard 214 to limit or prevent occupant compartment damage in single vehicle crashes (see Section 9.4) - if the damage to the occupant compartment is reduced, so, too, will be damage to the greenhouse.

Thus, the NCSS data do not rule out hypothesis (4), perhaps even providing a modest amount of support for it. But they certainly do not suggest that hypothesis (4) is a major factor in Standard 214's effectiveness in single vehicle crashes.

9.8 Occupant ejection and related damage phenomena

Hypothesis (5) of Section 9.1 was that Standard 214 might reduce ejection of occupants through doors because beams help preserve the structural integrity of doors and reduce stresses on door components such as latches and hinges. In other words, Standard 214 reduces the likelihood of a door being dented inwards (viz., by deflecting fixed objects and by increasing crush resistance in multivehicle crashes) which, in turn, may reduce the tension on latches and hinges below their failure point, which, finally prevents the door from opening or separating from the rest of the car.

Hypothesis (5) did not appear in the literature prior to the publication of this report. The remarkable reductions of occupant ejection attributable to Standard 214, which will be presented in this section, are one of the most surprising results of the evaluation.

Before presentation of the data, it should be pointed out that the reduction of ejection is not claimed to be purely a consequence of side door beams, alone. To some extent, it may also be a consequence of improvements made to door components or pillars, simultaneous with the installation of beams, to facilitate compliance with Standard 214 (see Section 4.2.3).

It should also be noted that

- o crashes in which the primary damage is due to rollover (4th letter of 1st CDC is 0) have been excluded.

- o 91 percent of the pre-Standard 214 cars on NCSS have door locks capable of meeting Standard 206. Furthermore, 99.7 percent of cars of the last 5 model years before beams were installed and 100 percent of cars of the last 2 model years before beams had such door locks (see Table 7-4). So the ejection reductions for post-Standard 214 cars cannot be attributed to any appreciable extent to Standard 206, not to any other safety device of the 1965-68 era, nor to an increase in belt usage (see Table 7-4).

In other words, the large reductions in ejection that will now be shown are taking place in genuine side impacts, not rollovers, and must be somehow attributable to Standard 214, not other standards.

Table 9-12 shows the percentages of crash-involved persons who were ejected through a door. Unweighted NCSS cases are used and ejections through unknown portals (about 23 percent of all ejections) are prorated among the known ejection routes.

TABLE 9-12

OCCUPANT EJECTION THROUGH DOORS, BY STANDARD 214 COMPLIANCE, UNWEIGHTED NCSS

Vehicle Age Range	In Single-Vehicle Side Impacts			In Multivehicle Side Impacts		
	n of Persons	Percent Ejected Through Doors**	Reduction for Std. 214 (%)	n of Persons	Percent Ejected Through Doors**	Reduction for Std. 214 (%)
Last 2 MY w/o beams	162	12.54	68*	649	1.75	12
First 2 MY w. beams	124	4.03		850	1.55	
Last 5 MY w/o beams	292	8.47	75*	1162	2.65	56*
First 5 MY w. beams	328	2.13		1865	1.16	
All cars without beams	355	8.54	56*	1529	3.43	72*
All cars with beams	518	3.74		2788	0.97	

*Statistically significant reduction ($\alpha = .05$)

**23 percent of ejections are through an unknown portal. They have been prorated among the known ejection portals.

There were large, statistically significant reductions in single-vehicle side impacts. The likelihood of door ejection was 68 percent lower in cars of the first 2 model years with beams than in cars of the last 2 model years without them. The reduction persisted when the range of model years was extended: 75 percent in the 5 year comparison and 56 percent in the all year comparison. In all 3 comparisons, the reduction is significant.

The picture is not so clear in multivehicle crashes (shown on the right side of Table 9-12). The likelihood of ejection in cars of the first 2 model years with beams was 12 percent lower than in the last 2 years without them; that reduction is not statistically significant. But in the longer term comparisons, the reductions are much larger: a significant 56 percent in the 5 year comparison and a significant 72 percent in the all-year comparison. Without additional information, it is impossible to judge whether these reductions are due to Standard 214 or some vehicle age-related trend.

The NCSS cases collected before April 1978 contain some additional data elements pertaining to vehicle damage. One of these is whether a door opened as a result of the impact. Obviously, a reduction in door opening is tantamount to a reduction in the risk of ejection through a door. Since door opening is much more common than occupant ejection, it should be easier to get statistically meaningful results.

Table 9-13 shows the percentages of all cars in which at least one door opened as a result of the impact. Reductions in side door opening were computed for both unweighted and weighted cases, but the statistical significance of the reduction was tested only for the unweighted cases.

TABLE 9-13

DOOR OPENING DURING IMPACT, BY STANDARD 214 COMPLIANCE, NCSS PRE-APRIL 1978

Vehicle Age Range	In Single-Vehicle Side Impacts: Unweighted n of Cars	Cars in which at Least 1 Door Opened	Reduction for Std. 214 (%): Based on Unweighted Cases	Based on Weighted Cases**	In Multivehicle Side Impacts: Unweighted n of Cars	Cars in which at Least 1 Door Opened	Reduction for Std. 214 (%): Based on Unweighted Cases	Based on Weighted Cases**
Last 2 MY w/o beams	60	18	7	20	237	38	21	10
First 2 MY w. beams	43	12			283	36		
Last 5 MY w/o beams	107	31	11	38	417	78	36*	30
First 5 MY w. beams	108	28			644	77		
All cars w/o beams	138	44	16	40	577	123	41*	27
All cars with beams	169	45			954	119		

*Statistically significant reduction ($\alpha = .05$)

**No statistical tests were performed in the weighted cases

The result based on unweighted cases is more statistically reliable when samples are small - especially in the 2 year comparison. The result based on weighted cases is less biased, although statistically imprecise, and is most meaningful when samples are large - i.e., in the 5 year and all-year comparisons.

For <u>single-vehicle</u> crashes, the results on sidedoor opening confirm the results on ejection. Consistently high reductions in the incidence of sidedoor opening are found for post-Standard 214 cars, based on the <u>weighted</u> cases: 20 percent in the 2 year comparison, 38 percent in the 5 year comparison and 40 percent in the all-year comparison. The reductions are not as high as those reported for door ejection in Table 9-12 (56-75 percent, using unweighted cases). The discrepancy could be due to chance alone, since Table 9-12 is based on small samples of ejectees. Or it could indicate that Standard 214 provides twofold protection against ejection in single vehicle crashes: (1) the incidence of door opening is reduced; (2) the tendency of Standard 214 to modify damage patterns and deceleration levels in crashes (see Section 9.3.2) may affect the timing and/or direction of occupant trajectories in a way that further reduces their likelihood of exiting through an open door. This explanation is just a conjecture, however, and would have to be confirmed by crash testing or other means.

In <u>multivehicle</u> crashes, Standard 214 cars appear to have consistently lower incidence of door opening than pre-standard cars. Based on the statistically more reliable <u>unweighted</u> case counts, cars of the first 2 model years with beams have a 21 percent lower incidence of door opening than cars of the last 2 years without them. That reduction, although nonsignificant, is more or less consistent with significant reductions of 36 percent in the 5 year comparison and 41 percent in the all-year comparison. The results based on weighted case counts are similar.

Thus, the results on door opening, in combination with the results on ejection, offer reasonably firm evidence that Standard 214 may have reduced the risk of ejection in nonfatal multivehicle crashes, perhaps by about 20 percent.

Another relevant data element recorded on the pre-April 1978 NCSS cases was the presence or absence of damage to door latches and hinges. A reduction in latch or hinge damage attributable to Standard 214 could be evidence that the standard helps reduce stress on door components.

Table 9-14 shows the percentages of cars in which at least one door latch or hinge was damaged in the impact. It is based on unweighted NCSS cases.

In <u>single-vehicle</u> crashes, cars of the first 2 model years with beams had a 19 percent lower incidence of latch or hinge damage than cars of the last 2 model years without beams. The reduction is statistically significant. Over the larger samples incorporating more model years, the reductions persisted but at a lower magnitude: 8 percent in the 5 year comparison and 11 percent in the all-year comparison. Neither of these are statistically significant.

The reductions in latch and hinge damage are more or less comparable to the degree of shift from compartment to fender damage (Table 9-6).

TABLE 9-14

DOOR LATCH OR HINGE DAMAGE DURING IMPACT, BY STANDARD 214 COMPLIANCE, UNWEIGHTED NCSS CASES, PRE-APRIL 1978

Vehicle Age Range	In Single-Vehicle Crashes			In Multivehicle Crashes		
	Unweighted n of Cars	Cars in which at Least 1 Latch or Hinge Damaged	Reduction for Std. 214 (%)	Unweighted n of Cars	Cars in which at Least 1 Latch or Hinge Damaged	Reduction for Std. 214 (%)
Last 2 MY w/o beams	62	49	19*	235	137	1
First 2 MY w. beams	42	27		273	158	
Last 5 MY w/o beams	108	79	8	416	246	5
First 5 MY w. beams	108	73		630	354	
All cars without beams	139	102	11	577	341	2
All cars with beams	169	110		937	544	

*Statistically significant reduction (one-sided $\alpha = .05$)

In other words Standard 214 does not show any specific propensity to protect door components that goes beyond its general tendency to shift the center point of vehicle damage from the compartment to the fender areas.

Table 9-14 does not show any substantial or significant reduction of latch or hinge damage in multivehicle crashes (observed reductions ranged from 1 to 5 percent in the 3 comparisons).

Data from the Fatal Accident Reporting System (FARS) confirm that Standard 214 helps prevent ejection in single-vehicle crashes. They show that Standard 214 was about equally effective in reducing ejection and nonejection fatalities (see Section 10.3).

Finally, what proportion of the overall effectiveness of Standard 214 can be attributed to a reduction of the risk of ejection? About 15 percent of nonfatal hospitalizations in single vehicle side impacts are due to ejection-related contacts (see Table 3-5). Since Standard 214 appears to be especially effective in reducing ejection (i.e., about 40-50 percent, vs. 25% overall injury reduction), it is likely that up to a quarter of the overall benefits in nonfatal single-vehicle crashes can be attributed to the decrease in ejections. Only 5 percent of nonfatal hospitalizations in multivehicle crashes are ejection related. Since Standard 214 appears to be twice as effective in reducing ejections as in preventing other types of injuries, it follows that a tenth of the total benefits in nonfatal multi-vehicle crashes can be attributed to a reduction of ejection risk.

Ejections account for nearly 25 percent of the fatalities in fixed object crashes (see Table 10-8). Since Standard 214 is about equally effective in preventing ejection and nonejection fatalities, about a quarter of the total life savings is due to a prevention of ejection.

9.9 Summary: why Standard 214 is effective

The analyses of vehicle damage patterns (Section 9.3), damage zones (9.4) and principal direction of force (9.5) showed that Standard 214 helps deflect a fixed object, but is not effective in deflecting a striking vehicle (hypothesis (2) of Section 9.1). On the other hand, Standard 214 was shown to be somewhat effective in reducing intrusion when a vehicle directly strikes a car in the door area (hypothesis (1)). Section 9.6 showed that Standard 214 apparently reduces sill override in multivehicle crashes (hypothesis (3)) but that this reduction accounts for a relatively small proportion of total benefits. Section 9.7 did not show Standard 214 to be effective in reducing the likelihood of greenhouse damage in fixed object collisions (hypothesis (4)). Finally several analyses in Section 9.8 showed Standard 214 to be quite effective in reducing the risk of occupant ejection (hypothesis (5)). A moderate proportion of casualties in fixed-object crashes and a smaller proportion in multivehicle crashes are ejection-related.

Based on the results of these analyses, it is possible to apportion the overall benefits of Standard 214 among the casualty-reducing mechanisms specified in the 5 hypotheses of Section 9.1. Table 9-15 shows the apportionment of benefits for fatalities and hospitalizations, in fixed-object

TABLE 9-15

CASUALTY REDUCTION ATTRIBUTABLE TO STANDARD 214, BY REDUCTION MECHANISM

Casualty Reduction Mechanism	Casualty Reduction Attributed to Standard 214 (%)			
	In Fixed Object Crashes		In Multivehicle Crashes	
	Nonfatal Hospitalizations	Fatalities	Nonfatal Hospitalizations	Fatilities
(1) Improved Crush Resistance	negl.	negl.	6	negl.
(2) Deflect striking object or vehicle	19	17	negl.	negl.
(3) Prevent sill override	N/A	N/A	1	negl.
(4) Prevent greenhouse damage	negl.	negl.	N/A	N/A
(5) Prevent ejection	6	6	1	negl.
OVERALL CASUALTY REDUCTION (%)	25	23	8	negl.

and multivehicle collisions. The overall casualty reduction, shown at the bottom of the table, is derived from Section 6.7, 7.8 or 10.4.1. In fixed-object crashes, both nonfatal and fatal, about a quarter of the overall benefits are attributed to a reduction of ejection; the remainder to Standard 214's capability of helping deflect fixed objects.

In multivehicle crashes, benefits are limited to nonfatal injuries. About three quarters of the benefits are attributed to an increase of crush resistance; one eighth, each, to a reduction of sill override and a reduction of ejection.

Although the apportionment of benefits in Table 9-15 is conjectural and not rigorous, there is remarkable harmony between the results of the damage analyses of this chapter, the overall casualty reduction found in Chapters 6 and 7, the specific types of injuries prevented (Chapter 10) and the crash test results and engineering considerations discussed in Chapter 4.

CHAPTER 10

WHEN IS STANDARD 214 EFFECTIVE?

ANALYSES OF INJURY SOURCES AND CRASH CONDITIONS

Chapters 6, 7 and 8 showed that Standard 214 reduced the overall risk of casualties in side impacts. In this chapter, effectiveness estimates are calculated separately for various subsets of the overall population at risk: by injury type (e.g., the effectiveness of Standard 214 in preventing thoracic injuries), by injury source (e.g., injuries due to contacts with structures on the side of the car), or by crash type (e.g., in collisions with poles/tress). National Crash Severity Study (NCSS) and Fatal Accident Reporting System (FARS) data are analyzed. Background information on NCSS and FARS may be found in Sections 7.1 and 6.2, respectively.

When the data files, especially NCSS, are partitioned there are usually not enough accident cases in each subgroup for statistically precise effectiveness estimates or for detailed analyses of possible biases. Despite uncertainties about the individual estimates, the results of this chapter are generally consistent with engineering intuition and the analyses of vehicle damage presented in Chapter 9: Standard 214 is found to be primarily effective in reducing injuries due to contact with side interior surfaces or due to occupant ejection; pelvic and leg injuries are more effectively mitigated than upper body injuries. In single vehicle crashes, Standard 214 seems to work best in collisions with guard rails or with tall, fixed objects (poles, trees, buildings). In multivehicle crashes, injuries are mitigated primarily when the impact is centered on the occupant compartment.

10.1 Effectiveness by impact location and occupant position

Sections 7.1 and 7.2 provided definitions, for use with NCSS data, of concepts such as:

- o a side impact
- o nearside or farside occupant
- o impact centered on the passenger compartment
- o fatal or hospitalizing injury
- o pre or post-Standard 214 cars
- o cars of the last 2 (or 5) model years before beams were installed
- o cars of the first 2 (or 5) model years after beams were installed
- o injury rates
- o a preliminary effectiveness estimate for Standard 214

The same definitions are used in this chapter, except where specified otherwise.

Two fundamental categorizations of side impacts are by location of impact and by occupant seat position relative to the damaged area. If the impact is centered on the occupant compartment, the structural characteristics of the door are immediately and directly relevant to the vehicles' performance in the crash. For the nearside occupant, seated adjacent to the struck door, the amount and velocity of the door's intrusion into the compartment is a critical factor in determining injury severity. Intuitively, it is expected that Standard 214 is most effective in crashes centered on the compartment, especially so for nearside occupants.

In single-vehicle crashes, however, it is not appropriate to compare the compartment-centered crashes of pre and post-Standard 214 cars, because Standard 214 is itself influential in determining the centerpoint of the damaged area. In Section 9.4 it was shown that one of the benefits of Standard 214 was to limit damage to the compartment and to spread it out to the fender areas. Thus, it is only meaningful to subdivide the single vehicle accident cases by occupant position relative to the damaged area.

Table 10-1 shows that Standard 214 was equally effective in mitigating the injuries of nearside and farside occupants in single vehicle crashes on NCSS. The injury rate of nearside occupants was reduced by 26 percent; of farside occupants, by 29 percent. The injury rates are based on the definitions of Sections 7.1 - 7.3, using "all pre-Standard 214 cars vs. all post-standard cars" (but excluding rollovers, convertibles, pickup cars and model years with possible mid-year beam installation, just as in Chapter 7). The injury rates are based on direct tabulation of weighted NCSS data, as in Section 7.3: no multivariate analyses of possible biases are performed.

The NCSS results parallel the FARS results, shown in Table 6-3, that Standard 214 is about equally effective in reducing fatalities of nearside and farside occupants (14% and 15% observed reductions). They are consistent with the conclusions based on analysis of damage patterns (Section 9.3.2) that Standard 214 should benefit farside as well as nearside occupants in single vehicle side impacts.

In <u>multivehicle</u> crashes it is more appropriate to compare the compartment-centered crashes of pre and post-Standard 214 cars because Standard 214 itself has little or no effect on the centerpoint of the damage (see Section 9.4). Table 10-2 shows that Standard 214 appears to be effective only in impacts where the <u>centerpoint</u> of the damage

TABLE 10-1

STANDARD 214 EFFECTIVENESS IN SINGLE VEHICLE CRASHES:

NEARSIDE VS. FARSIDE OCCUPANTS, NCSS

	N of Persons	Injury Rate (%)	Reduction for Standard 214 (%)
NEARSIDE OCCUPANTS			
Pre-Standard 214	540	17.41	26
Post-Standard 214	960	12.92	
FARSIDE OCCUPANTS			
Pre-Standard 214	653	12.86	29
Post-Standard 214	1114	9.16	

is located within the passenger compartment zone: here the injury reduction is 22 percent. There is little or no effectiveness (4% observed) in crashes where the centerpoint of the damage is in the fender zones, despite the fact that, according to Table 9-7, half of these crashes have damage envelopes partially overlapping the compartment. In other words, for Standard 214 to have an effect, it is apparently not enough to have damage to the compartment: the damage must be centered on the compartment.

Table 10-3 further subdivides the persons involved in compartment crashes by seating location: nearside vs. farside. The injury reduction for Standard 214 cars is 25 percent for nearside occupants and almost as great - 21 percent - for farside occupants. From these results (and considering the sample sizes on which they are based) it seems likely that Standard 214 is effective for farside occupants in compartment impacts, perhaps even as effective as for nearside occupants. That possibility is not necessarily consistent with engineering intuition and the analysis of damage patterns (Section 9.3.3), which suggest that Standard 214 would be effective primarily for nearside occupants. The next section - analysis of injury sources and types - includes a closer look at the farside occupants.

Of course, even if Standard 214 should turn out to be effective for farside occupants, the primary benefits of the standard accrue to nearside occupants, who account for 60 percent of the casualities in compartment impacts (see Table 10-3).

10.2 Effectiveness by injury source and body region

The NCSS cases contain detailed information on the cause and nature of an occupant's injuries. Up to 6 injuries are coded per occupant.

TABLE 10-2
STANDARD 214 EFFECTIVENESS IN MULTIVEHICLE CRASHES:
OCCUPANT COMPARTMENT IMPACTS VS. OTHER CRASHES, NCSS

	N of Persons	Injury Rate (%)	Reduction for Standard 214 (%)
IMPACTS CENTERED ON OCCUPANT COMPARTMENT			
Pre-Standard 214	2244	11.54	22
Post-Standard 214	4206	8.99	
NOT CENTERED ON COMPARTMENT			
Pre-Standard 214	4332	4.52	4
Post-Standard 214	8139	4.36	

TABLE 10-3
STANDARD 214 EFFECTIVENESS IN MULTIVEHICLE COMPARTMENT
IMPACTS: NEARSIDE VS. FARSIDE OCCUPANTS, NCSS

	N of Persons	Injury Rate (%)	Reduction for Standard 214 (%)
NEARSIDE OCCUPANTS IN COMPARTMENT IMPACTS			
Pre-Standard 214	1044	14.66	25
Post-Standard 214	2108	11.01	
FARSIDE OCCUPANTS IN COMPARTMENT IMPACTS			
Pre-Standard 214	1200	8.83	21
Post-Standard 214	2098	6.96	

The information includes the contact source within (or outside) the vehicle that caused the injury and the body region injured.

10.2.1 Definitions

For the analyses that follow, the codes for contact sources have been grouped into 4 categories:

- Frontal interior surfaces - NCSS codes 1-14, which include the instrument panel, steering assembly, windshield, etc.
- Side interior surfaces - NCSS codes 15-24 and 32, which include the inside of the door and its attachments, the pillars, side windows and their frames and the roof side rails.
- Exterior objects - NCSS codes 43-49, which are mostly ejection-related contacts.
- Other known contacts - NCSS codes 25-31, 33-42 and 90, which include seats, occupants, cargo, roof, floor, rear surface and noncontact injuries.

The regions of the body have been grouped into 3 categories:

- Head, face and neck
- Thorax, shoulders, upper extremities and back
- Lower body including abdomen, pelvis and lower extremities

The analyses are limited to occupants who were killed or hospitalized, but up to 3 injuries per occupant may be included. The occupant's most severe injury is always included. The 2nd or 3rd most severe injuries are also eligible for inclusion if they are

- AIS ≥ 3 or

o the same AIS as the most severe injury.

The injuries included under this scheme are referred to as "fatal or hospitalizing injuries."

In the analyses that follow, rates are presented for the number of injuries (of a specific type) per 1000 crash-involved occupants. They are not, strictly speaking, occupant injury rates in the sense of Chapter 7, since more than one injury is counted for some occupants. Finally, the contact point and/or specific injury is unknown for about 50 percent of the fatal or hospitalizing injuries sustained by NCSS occupants. The rates shown in the tables that follow are based only on the known cases and are therefore, on the average, understated by 50 percent.

The caveat stated at the beginning of this chapter - viz., that effectiveness measures are in many cases not statistically precise - applies especially to the results on injury sources and body regions, in part because the high rate of missing data (50%) cuts the effective sample size in half.

10.2.2 Injury sources and types in single vehicle crashes

Table 10-4 shows the reduction, for post-Standard 214 cars, of injuries due to various contact sources (in the top section); injury reduction by body region (in the middle section); by contact sources and body region (in the lowest section). For example, there were 1193 occupants of pre-standard cars involved in single-vehicle side impacts. These persons had, among them, a total of 67 injuries, due to contact with components in the front of the compartment (steering wheel, windshield, etc.), that would have resulted in

TABLE 10-4

INJURY RATES IN SINGLE-VEHICLE SIDE IMPACTS

BY CONTACT SOURCE AND BODY REGION, BY STANDARD 214 COMPLIANCE,

NCSS

	Serious[1] Injuries per 1000 Crash Involved Persons		Reduction for Standard 214 (%)
	Pre-Std. 214[2]	Post-Std. 214[3]	
BY CONTACT SOURCE			
Frontal surfaces	56.16	40.98	27
Side surfaces	70.41	45.32	36
Exterior to car	25.98	9.64	63
Other	15.08	27.00	-79
BY BODY REGION			
Head	70.41	57.86	18
Thorax	47.78	37.13	22
Lower body	49.46	27.97	43
BY CONTACT SOURCE AND BODY REGION			
Frontal surfaces			
Head	20.12	16.39	19
Thorax	20.12	14.46	28
Lower body	15.93	10.13	36
Side surfaces			
Head	25.15	18.80	25
Thorax	19.28	15.43	20
Lower body	25.98	11.09	57

1. Resulting in fatality or hospalization
2. N of crash-involved persons= 1193
3. N=2074

fatality or hospitalization (see Section 10.2.1). That amounts to a rate of 56.16 serious injuries per 1000 exposed persons. The occupants of post-standard cars had a rate of 40.98 injuries per 1000 persons, due to frontal contact points. That is a 27 percent reduction relative to the pre-standard injury rate.

Table 10-4 shows that Standard 214 was most effective in reducing ejection-related injuries: it reduced injuries due to contact with exterior objects by 63 percent. Standard 214 was quite effective (36 percent) in reducing injuries due to contacts with side surfaces within the vehicle; moreover, since those contacts had been the predominant source of injury (70.41 per 1000 persons in pre-standard cars) they are the type for which Standard 214 has the largest benefits, in absoulute terms (a reduction of 25.09 injuries per 1000 persons). Standard 214 also appears to be effective in reducing injuries due to frontal contacts - although the observed 27 percent reduction may be due, in part, to other safety devices, age biases, etc. Finally, the large observed increase of injuries due to other contacts (79%) would appear to be an artifact of the analysis and not a result of Standard 214: since the standard has eliminated large numbers of side, ejection, and frontal injuries, the remaining types of injuries have become more likely to meet the threshold defined in Section 10.2.1. For example, while in a pre-standard car they might not have been one of the occupant's 3 most severe injuries, they might be so in a post-standard car.

Thus, the results on injury contact sources are entirely consistent with the findings of Chapter 9, viz., that Standard 214 has significantly reduced ejection (Section 9.8) and has modified a vehicles' response to impact with a fixed object in a manner that should not only substantially reduce injuries due to side contacts but could even affect frontal contact injuries (Section 9.3.2).

Table 10-4 shows that Standard 214 has reduced injuries to all body regions in single vehicle crashes. The largest reduction (43%) was for lower body injuries, but there were also reductions for the thorax (22%) and head (18%). Since head injuries are the predominant type of fatal lesion, their prevention is the key to fatality reduction.

Even more insight is gained by classifying the injuries by body region and contact point (although the rates are less statistically precise and should be interpreted with caution). Table 10-4 shows that Standard 214 was most effective in preventing the injuries it was intended to prevent: there was a 57 percent reduction of lower body injuries due to side contacts. That type of injury is often a direct result of contact with intruding surfaces and, as was shown in Section 9.3.2, Standard 214 significantly reduced intrusion in single-vehicle crashes. But there was also a sizable reduction of head injury (25%) and thoracic injury (20%) due to contact with side surfaces.

Table 10-5 is identical to Table 10-4, except that injury rates are measured separately for nearside and farside occupants. The injury reductions are shown side by side, with nearside occupants' results on the left. It is possible to compare, for each type of injury, the benefits of Standard 214 for the two groups of occupants.

Specifically, Table 10-1, which only showed overall injury

TABLE 10-5

INJURY RATES IN SINGLE-VEHICLE SIDE IMPACTS,

BY CONTACT SOURCE AND BODY REGION, BY STANDARD 214 COMPLIANCE,

NEARSIDE VS. FARSIDE OCCUPANTS, NCSS

	NEARSIDE			FARSIDE		
	Serious[1] Injuries per 1000 Crash-Involved Persons		Reduction for Standard 214 (%)	Serious[1] Injuries per 1000 Crash-Involved Persons		Reduction for Standard 214 (%)
	Pre-Std. 214[2]	Post-Std. 214[3]		Pre-Std. 214[4]	Post-Std. 214[5]	
BY CONTACT SOURCE						
Frontal surfaces	51.85	28.13	46	59.72	52.06	13
Side surfaces	112.96	65.63	42	35.22	27.83	21
Exterior to car	33.33	14.58	56	19.91	5.39	73
Other	14.81	28.13	-90	15.31	26.03	-70
BY BODY REGION						
Head	94.44	65.63	31	50.54	51.17	-1
Thorax	44.44	37.50	16	50.54	36.80	27
Lower body	74.07	33.33	55	29.10	23.34	20
BY CONTACT SOURCE AND BODY REGION						
Frontal surfaces						
Head	16.67	8.33	50	22.97	23.33	-2
Thorax	16.67	11.46	31	22.97	17.06	26
Lower body	18.52	8.33	55	13.78	11.67	15
Side surfaces						
Head	42.59	30.21	29	10.72	8.97	16
Thorax	22.22	18.75	16	16.84	12.57	25
Lower body	48.75	16.67	65	7.66	6.28	18

1 Resulting in fatality or hospitalization

2 N of crash-involved persons = 540

3 N=960

5 N=1114

rates, did not indicate any significant difference in Standard 214 effectiveness between nearside and farside occupants. Engineering intuition, though, would suggest, at the very least, different reasons for effectiveness for the two groups and, very likely, greater effectiveness for nearside occupants, who are more vulnerable to contact with intruding surfaces. The more detailed injury rates in Table 10-5 give a much better understanding of how the standard works and confirm engineering intuition.

For nearside occupants, the most common injury source, by far, is contact with side surfaces (113 serious injuries per 1000 exposed occupants of pre-standard cars). Standard 214 reduced these injuries by 42 percent. Side contacts are only the no. 2 injury source for farside occupants (35 per 1000) and Standard 214 was half as effective (21%) as it was for the nearside occupants.

Standard 214 was highly effective in reducing ejection related injuries for both nearside (56%) and farside (73%) occupants. For the latter group, this reduction accounts for close to half of the overall benefits. For the nearside occupants, it accounts for fewer benefits, in absolute terms, than the side and frontal contact injury reductions.

The most frequent contact point-body region combination for nearside occupants in pre-standard cars was lower body injury in side surface contacts - the type of injury most readily attributable to contact with intruding surfaces. Standard 214 reduced these injuries by 65 percent - the highest reduction for any of the combinations. The corresponding reduction for farside occupants was much lower (18%), consistent with engineering intuition. In the other side contact injuries (head and thorax), the discrepancy between nearside and farside occupants was less, again consistent with intuition.

Nearside occupants' head injuries were substantially reduced in both side (29%) and frontal (50%) contacts. This benefit is consistent with Standard 214's effect of helping to keep fixed objects away from the passenger compartment (Section 9.4), especially the greenhouse area (Section 9.7). It could be an important reason why Standard 214 saves lives in single vehicle crashes.

Thus, for farside occupants, the principal sources of benefits are reduction of ejection and overall damage pattern amelioration. Nearside occupants obtain both of these benefits, but even more importantly, they avoid injuries due to contact with intruding surfaces and, possibly, head injuries.

10.2.3 Injury sources and types in multivehicle crashes

Table 10-6 displays injury rates by contact source and body region in all types of multivehicle side impacts. The majority of the injuries are due to contacts with side surfaces and Standard 214 has reduced these by 10 percent (as compared to a 36% reduction in single-vehicle crashes on Table 10-4). Ejection-related injuries are reduced by 57 percent, but they only account for a small fraction of overall casualties. There was no reduction of injuries due to contact with frontal surfaces. These results are consistent with the conjectures of Sections 9.3.3 and 9.8, viz., that there would be a moderate reduction of side contact injury, a substantial reduction of ejection and few other benefits.

TABLE 10-6

INJURY RATES IN MULTIVEHICLE SIDE IMPACTS,

BY CONTACT SOURCE AND BODY REGION, BY STANDARD 214 COMPLIANCE, NCSS

	Serious Injuries[1] per 1000 Crash Involved Persons		Reduction for Standard 214 (%)
	Pre-Std. 214[2]	Post-Std.[3]	
BY CONTACT SOURCE			
Frontal surfaces	20.99	21.06	0
Side surfaces	39.23	35.16	10
Exterior to car	3.80	1.62	57
Other	10.80	9.48	12
BY BODY REGION			
Head	24.03	24.78	-3
Thorax	30.26	25.92	14
Lower body	20.53	16.61	19
BY CONTACT SOURCE AND BODY REGION			
Frontal surfaces			
Head	6.84	8.59	-25
Thorax	8.82	8.34	5
Lower body	5.32	4.13	22
Side surfaces			
Head	10.19	10.13	1
Thorax	17.18	14.34	17
Lower body	11.86	10.69	10

1. Resulting in fatality or hospitalization
2. N of crash-involved persons = 6576
3. N=12345

An important result of Table 10-6 is that head injuries were not affected, neither overall (3% increase) nor, specifically, in contacts with side surfaces (1% reduction). Since head injuries account for the majority of fatalities, this severely limits the potential life-saving benefits of Standard 214 in multivehicle crashes.

The benefits of Standard 214 appear to be limited to reduction of thoracic (17%) and lower body (10%) injuries due to contact with side surfaces. These are the types of injuries most likely to involve contact with an intruding surface and, according to the findings of Sections 9.3.3 and 9.6, the type where Standard 214 is most likely to be effective.

Table 10-7 is limited to impacts centered on the occupant compartment (the only multivehicle crashes in which Standard 214 is effective, according to Table 10-2). Moreover, injury rates are calculated separately for nearside and farside occupants and tabulated side-by-side. Table 10-7 is of considerable importance, because Table 10-3, which was based on overall injury rates, showed injury reductions for farside occupants (21%) that were almost as high as for nearside occupants (25%). That result was not consistent with engineering intuition and the findings of Chapter 9, which suggested effectiveness only for nearside occupants. But the detailed injury breakout of Table 10-7 suggests that the overall reduction for farside occupants is perhaps largely unrelated to Standard 214. Specifically, Table 10-7 shows that the overwhelming majority of serious injuries for nearside occupants in compartment crashes is due to contact with side surfaces. Virtually the entire benefit of Standard 214 accrues from a 31 percent reduction of these injuries. Side contacts are a relatively unimportant injury source for farside occupants, and at best marginally (7%) reduced by Standard 214.

TABLE 10-7

INJURY RATES IN MULTIVEHICLE COMPARTMENT IMPACTS,

BY CONTACT SOURCE AND BODY REGION, BY STANDARD 214 COMPLIANCE,

NEARSIDE VS. FARSIDE OCCUPANTS, NCSS

	NEARSIDE			FARSIDE		
	Serious[1] Injuries per 1000 Crash-Involved Persons		Reduction for Standard 214 (%)	Serious[1] Injuries per 1000 Crash-Involved Persons		Reduction for Standard 214 (%)
	Pre-Std. 214[2]	Post-Std. 214[3]		Pre-Std. 214[4]	Post-Std. 214[5]	
BY CONTACT SOURCE						
Frontal surfaces	22.99	24.19	-5	38.33	38.13	1
Side surfaces	136.02	93.93	31	20.00	18.59	7
Exterior to car	4.79	1.42	70	2.50	0.95	62
Other	9.58	12.81	-34	20.83	9.06	57
BY BODY REGION						
Head	36.40	34.62	5	34.17	30.51	11
Thorax	72.80	55.50	24	28.33	24.79	13
Lower body	64.18	42.22	34	19.17	11.44	40
BY CONTACT SOURCE AND BODY REGION						
Frontal surfaces						
Head	2.87	8.54	-198	15.83	15.73	1
Thorax	11.49	9.96	13	14.17	16.21	-14
Lower body	8.62	5.69	34	8.33	6.20	26
Side surfaces						
Head	24.90	19.92	20	9.17	10.01	-9
Thorax	57.47	41.27	28	6.67	5.24	21
Lower body	53.64	32.73	39	4.17	3.34	20

1 Resulting in fatality or hospitalization

2 N of crash-involved persons = 1044

3 N=2108

4 N=1200

5 N=2098

Ejection-related injuries are substantially reduced for both nearside (70%) and farside (62%) occupants, but the absolute benefits are small because ejection accounts for fewer than 5 percent of the injuries.

Standard 214 had no effect on frontal contact injuries for either nearside (5% increase) or farside (1% reduction) occupants. The small increase observed for nearside occupants could be an artifact of the analysis - the big reduction in side contact injuries could have made room for frontal contacts to meet the "serious" injury threshold defined in Section 10.2.1. Similarly, the 34 percent increase, for nearside occupants, of injuries from "other" sources is probably an artifact.

The only substantial injury reduction for farside occupants, in absolute terms, was on the injuries due to "other" sources (57%). Predominant among those sources were noncontact injury (e.g. whiplash) and contacts with the front seatback. It is most doubtful that Standard 214 could have had much effect on either of them. Thus, the bulk of the observed injury reduction for farside occupants is probably due to statistical chance or reasons unrelated to Standard 214.

For nearside occupants in compartment crashes, on the other hand, Standard 214 had substantial benefits in preventing those injuries it was designed to prevent: lower body (39% reduction) and thoracic (28%) injuries due to contact with side surfaces. They are the type of injury which, for a nearside occupant in a compartment crash, is very likely to involve contact with an intruding side structure. (Although comparable levels of effectiveness were found for farside occupants on both of these contact-body region combinations, the absolute benefits are 90-95% less, because the injuries are much

Finally, Table 10-7 presents a possibility that Standard 214 may have reduced head injuries, due to side contacts, for nearside occupants. The observed reduction is 20 percent and is less than the thoracic and lower body injury reductions. Moreover, a 20 percent reduction for nearside occupants in compartment crashes is difficult to reconcile with the corresponding 1 percent reduction, on Table 10-6, for all multivehicle crashes or with the 5 percent reduction, for all types of nearside occupants' head injuries, in Table 10-7. Most likely, the 20 percent is exaggerated as a result of sampling error.

Thus, Table 10-7 provides strong support to the conjecture that the benefits of Standard 214 in multivehicle crashes are mainly limited to nearside occupants in compartment impacts and, there, to torso and leg injuries due to contact with intruding side surfaces.

10.3 Reduction of ejection fatalities

The evidence from Sections 9.8 and 10.2.2 shows that Standard 214 has been effective in reducing occupant ejection in nonfatal single-vehicle crashes - at least, in the crashes on NCSS. The Fatal Accident Reporting System (FARS) data indicate, as will be shown here, that Standard 214 is likewise effective in reducing fatal ejections.

The procedure for computing effectiveness from FARS, as developed in Section 6.3 and, more specifically, Section 6.3.2, is to tabulate frontal and side impact fatalities for the last two model years before beams were installed and for the first two model years with beams. The reduction in side impact fatalities relative to the reduction in frontal fatalities is a measure of the effectiveness of Standard 214.

TABLE 10-8

EJECTION AND NONEJECTION SIDE IMPACT FATALITIES VS. FRONTAL FATALITIES IN FIXED-OBJECT CRASHES, FIRST TWO YEARS WITH BEAMS VS. LAST TWO YEARS WITHOUT THEM, FARS 1975-78, 81

	Fatality Counts			
	Frontal	Side Nonejectees	Frontal	Side Ejectees
Last 2 model years without beams	3179	1233	3179	381
First 2 model years with beams	2971	898	2971	271
Side impact fatality reduction	22%		24%	
Chi-square	24.20 (signif., α=.05)		10.75 (signif.)	

If the ejection and nonejection side impact fatalities are tabulated separately, it is possible to compute, separately, the reductions of ejection and nonejection fatalities (relative to frontal fatalities). This is done in Table 10-8, which is analogous to Table 6-3, except that ejectees (full or partial ejection) have been separated from nonejectees (not ejected or unknown if ejected). Moreover Table 10-8 is limited to single-vehicle side impacts involving fixed objects - the type where Standard 214 is likely to be effective (see Section 10.4). In other words, it excludes crashes that are basically rollovers with primary damage to the side of the car, other noncollisions and collisions with trains (codes 1 - 11 for First Harmful Event in 1975-78, for Most Harmful Event in 1981). Finally, it is limited to calendar years 1975-78 and 1981. (Although the information could have been obtained for 1979-80 as well, it was not extracted during the preparation of this report.)

Table 10-8 shows that frontal fatalities of all types in single vehicle crashes were almost the same in the last 2 model years before beams were installed (3179) as in the first 2 model years with beams (2971). But ejection fatalities in side impacts with fixed objects dropped from 381 to 271. This is a statistically significant 24 percent reduction of fatal ejections, relative to the frontals. The reduction occurred over a short time span (2 years after vs. 2 years before Standard 214) during which few changes were made in vehicles other than Standard 214 - thus, the reduction of fatal ejections can be attributed, almost in its entirety, to Standard 214.

Table 10-8 also shows that Standard 214 reduced nonejection fatalities in side impacts with fixed objects by a significant 22 percent - almost the same as the reduction of fatal ejections.

Since, as Table 10-8 shows, ejectees comprise about a quarter of the fatalities in side impacts with fixed objects and since Standard 214 appears to be about equally effective in reducing ejection and nonejection fatalities, it may be concluded that about a quarter of the life-saving benefits of Standard 214 in fixed object collisions are due to prevention of ejection. Three quarters of the benefits accrue to persons who remain within the vehicle in crashes (see Table 9-15).

10.4 Effectiveness by type of object or vehicle contacted

Both NCSS and FARS provide strong evidence that Standard 214 is effective in what may be called a "classical" single vehicle side impact: a collision of a moving car with a tall, rigid, immovable object such as a pole, large tree or building. Standard 214 is also effective in collisions with guard rails. But it has little or no effect in other types of crashes that, by the definitions of this report, are called "single vehicle side impacts": rollovers with primary damage to the side of the car, trains hitting cars in the side, or complex off-road excursions.

The NCSS sample is too small for a statistically reliable measure of Standard 214 effectiveness, in multivehicle collisions, as a function of the size of the striking vehicle. It suggests that, perhaps, the standard is most effective if the striking vehicle is a small car or a light truck.

10.4.1 Fatality reduction by type of object struck

In Table 6-3, the overall effectiveness of Standard 214 in single vehicle side impacts is calculated by comparing side and frontal single-vehicle crash fatalities for cars of the first 2 model years with beams versus cars of the last 2 model years without them, based on FARS data for

1975-81. In Table 10-9, the side impact fatalities are subdivided into 7 groups, based on the type of object struck. The effectiveness of Standard 214 is calculated separately for each of the groups by comparing the fatalities for that group alone to those in all types of frontal single-vehicle crashes.

Since 7 years of FARS data contain a large number of fatalities, even when restricted to just 2 model years before and after beam installation, they accurately indicate where Standard 214 is effective and where it is not.

The type of crash that accounts for nearly two-thirds of single-vehicle side impact fatalities is a collision with a tall, rigid, immovable, massive object such as a large tree, pole or wall. The object extends from the ground to above the roof of a car and can engage all components of the car's side structure, including the door, sill and roof rails. Since the object is immovable and since sill override is impossible, the door is not liable to being displaced at a faster rate than other components of the side structure (see Section 3.2). The potential benefits of Standard 214, if any, are not in slowing down door intrusion relative to the rest of the side structure. They are in deflecting the vehicle from the object, spreading out the damage, reducing damage to the passenger compartment (especially the greenhouse) and preventing door opening (see Chapter 9).

Table 10-9 shows that Standard 214 has reduced fatalities in collisions with tall fixed objects - presumably indicating that the standard has accomplished the goal of deflection of these objects. Tall objects are further subdivided into two types: wide and narrow. Wide objects, such as walls, buildings and underpasses, are less likely to penetrate deeply into a car than narrow objects. As a result, if the crash has any kind of oblique

TABLE 10-9

STANDARD 214 FATALITY REDUCTION IN SINGLE VEHICLE SIDE IMPACTS, BY TYPE OF OBJECT STRUCK, FARS 1975-81

(Based on comparison with frontal fatalities; first 2 MY with beams vs. last 2 MY without beams)

General Description of Object	Specific List of Objects	FARS Codes*	Fatalities Last 2 MY w/out Beams	Fatalities First 2 MY w. Beams	Reduction fo Standard 214 (%)
ALL FRONTAL SINGLE-VEH. FATALITIES			4325	4303	
Tall, wide objects	walls, buildings, underpasses	18,20,32	110	59	46
Tall, narrow objects	trees, poles	25-29	1436	1135	21
Obj. likely to interact w. beams	guard rails	24	133	95	28
SUBTOTAL: TALL FIXED OBJECTS AND GUARD RAILS			1679	1289	23
Offroad excursions, low objects	embankments, culverts, ditches, abutments	17,19,21,22, 30,31,33	245	253	-4
Collisions with trains		10	265	284	-8
Rollovers & other noncollisions	rollovers, fires, immersions	1-7	195	199	-3
Collisions with moveable objects	fences, animals	8,9,11,16,23	43	45	-5
SUBTOTAL: ALL OTHER SINGLE-VEH. SIDE IMPACTS			748	781	-5

*First harmful event in 1975-78; most harmful event in 1979-81

**Reduction relative to frontal single-vehicle fatalities: 1 - ((Post/Pre)/(4303/4325)) force component, Standard 214 has an especially good opportunity to deflect the object and/or hold the door structure together. Indeed, Table 10-9 shows that Standard 214 reduced fatalities in collisions with tall, wide objects by 46 percent. Tall, narrow objects such as trees and poles are by far the most common source of fatalities in single vehicle side impacts. If the crash occurs at high speeds and/or close to a 90 degree angle, these objects will demolish a car and there isn't much that Standard 214 could do about it. Nevertheless, there were enough fatalities, in pre-Standard 214 cars, at low enough speeds and sufficiently oblique angles that Standard 214 reduced fatalities by 21 percent - in absolute terms, accounting for three quarters of the life-savings for Standard 214.

Guard rails are a special type of fixed object: they are set at a level likely to engage a side door beam while missing the roof rails and, possibly, the sill. Moreover, they are long and simultaneously engage doors, pillars and fenders. If beams are effective in deflecting objects, they should be especially effective in helping a guard rail perform its intended purpose of deflecting a car. Indeed, Table 10-9 shows a 28 percent fatality reduction for Standard 214 in collisions with guard rails.

The aggregate fatality reduction for Standard 214 in collisions with tall fixed objects and guard rails is 23 percent. The reduction is statistically significant (chi-square = 36.71, $p < .05$). These crashes, prior to Standard 214, accounted for 69 percent of the deaths in single vehicle side impacts.

In the remaining 31 percent of crashes classified as "single vehicle side impacts" - crashes of a type where beams generally have no opportunity to deflect objects - Standard 214 has little or no effect. In fact, a 5 percent increase in fatalities was observed; the increase was not significant (chi-square = 0.76, $p \geqslant .05$).

These crashes are subdivided among 4 groups: there are collisions with low fixed objects, many of which would appear to be complex offroad excursions with multiple impacts to embankments, culverts, ditches, etc. (A small proportion of these crashes were collisions with abutments, which in some cases could have been a single impact with an object tall enough to engage the beams.) The observed effectiveness for Standard 214 in collisions with low objects was -4 percent.

The second subgroup, collisions with trains, accounts for 11 percent of "single vehicle" side impact fatalities. These collisions often involve a fast-moving train hitting a car at an angle close to 90 degrees, so there is relatively little opportunity for beams to help the car be deflected. The observed effectiveness of Standard 214 was -8 percent.

Rollovers and other noncollisions with principal damage to the side of the car were not excluded from the FARS data analyzed in Chapter 6. The observed fatality reduction for Standard 214 was -3 percent.

Finally, collisions with yielding objects (fences) or nonfixed objects (e.g., animals) account for a small number of fatalities - typically involving complex offroad excursions or unusual fatality mechanisms. The observed fatality reduction for Standard 214 was -5 percent.

The significant fatality reduction in crashes where Standard 214 could be expected to have some benefit and the absence of a reduction in other crashes are strong evidence that the life savings attributed to Standard 214 by the FARS analyses are, in truth, due to that standard.

10.4.2 Serious injury reduction by type of object struck

Table 10-10 shows the NCSS injury rates in pre- and post-Standard 214 cars in single-vehicle side impacts, subdivided by type of object contacted. The effectiveness estimates are remarkably consistent (although statistically less precise) with the FARS results of Table 10-9.

Occupants of post-standard cars had a 25 percent lower rate of fatality or hospitalization than pre-standard car occupants in collisions with tall fixed objects - poles, trees and buildings. It is nearly the same reduction as was found on FARS. These collisions accounted for 79 percent of the pre-Standard 214 fatalities and hospitalizations in single vehicle side impacts on NCSS.

An 80 percent injury reduction was observed for Standard 214 in collisions with guard and bridge rails. The reduction, which is based on small samples and is not statistically precise, is consistent with the high fatality reduction, on FARS, in guard rail impacts.

In NCSS, as on FARS, there was no effectiveness in collisions with low fixed objects (culverts, ditches, embankments, abutments - observed reduction -21 percent) or moveable objects (fences, small trees, small posts, etc. - observed reduction -14 percent).

10.4.3 Serious injury reduction by size/type of striking vehicle

Table 10-11 shows the NCSS injury rates in multivehicle crashes, subdivided by type of striking vehicle: small cars, large cars, light truck,

TABLE 10-10

STANDARD 214 INJURY* REDUCTION IN SINGLE VEHICLE SIDE IMPACTS, BY TYPE OF OBJECT STRUCK, NCSS

Type of Object Struck	NCSS Codes	Pre-Standard 214		Post-Standard 214		Reduction for Standard 214 (%)
		N	% Injured*	N	% Injured*	
Large trees, poles or buildings	21-23, 28	769	19.2	1281	14.4	25
Guard or bridge rails	29, 30	103	18.4	320	3.8	80
Culverts, ditches, embankments, abutments	25-27	123	8.9	277	10.8	-21
Moveable objects, small trees	20, 24	253	3.6	344	4.1	-14

*Fatality or hospitalization

TABLE 10-11

STANDARD 214 INJURY* REDUCTION IN THE STRUCK VEHICLE IN MULTI-VEHICLE SIDE IMPACTS, BY SIZE/TYPE OF STRIKING VEHICLE, NCSS

Striking Vehicle	NCSS Codes	ALL MULTIVEHICLE CRASHES					NEARSIDE OCC. IN COMPARTMENT CRASHES				
		Pre-Std. 214		Post-Std. 214		Reduction for Std. 214	Pre-Std. 214		Post-Std. 214		Reduction for Std. 214
		N	% Inj.	N	% Inj.	(%)	N	% Inj.	N	% Inj.	(%)
Small car	1-2	1865	4.34	3624	3.34	23	241	12.03	394	8.12	33
Large car	3-5	3375	6.46	5962	5.85	9	629	10.81	1047	10.70	1
Light truck	6	633	11.85	1394	9.18	23	79	27.85	281	15.66	44
Heavy truck/bus	7-12	257	19.46	469	21.32	-10	50	30.00	80	33.75	-13

*Fatality or hospitalization

heavy truck/bus. Injury reduction in all types of multivehicle side impacts is shown on the left half of the table; for nearside occupants in compartment impacts on the right side.

The observed injury reduction for Standard 214 is high when the striking vehicle is a small (subcompact or compact) car or a light truck. With small cars as the striking vehicle, the reduction is 23 percent in all crashes and 33 percent for nearside occupants in compartment crashes. When light trucks are the striking vehicle, the injury reduction for struck post-Standard 214 cars is 23 percent overall, 44 percent for nearside occupants in compartment crashes.

When the striking vehicle is a larger car, the effect on injury rates in the struck car observed for Standard 214 is a 9 percent reduction overall and a 1 percent reduction for nearside occupants in compartment crashes. When the striking vehicle is a heavy truck or bus, a small increase in the struck car's injury rate is observed for Standard 214 (10 percent overall, 13 percent for nearside occupants in compartment crashes).

The NCSS sample sizes are too small for these differences of observed effectiveness to be statistically significant. This is especially the case for the nearside occupants in compartment crashes, where, moreover, the pre-standard injury rates for large cars and heavy trucks (as the striking vehicle) seem anomalously low in comparison with small cars and light trucks. If those two injury rates had been higher, the effectiveness would not have been so low.

If the observed differences of effectiveness are, to any extent, reflective of real differences rather than purely a result of statistical chance, the following explanations could be offered:

When a small car is the striking vehicle, there might be certain advantages for Standard 214. The small vehicle might be built low enough that there is a good chance of sill contacts; moreover its light frontal structure is more easily forced downwards, by the struck car's beam, into the sill (see Section 9.6). Also, smaller cars tend to have softer frontal structures and the struck car's beams may be strong enough to effectively resist being crushed by that structure.

If a light truck is the striking vehicle, it will almost always be high enough to significantly engage the struck car's beam and, in many cases, high enough to override the sill. Thus, the beam in many cases gets no "help" from the sill or other structures in resisting intrusion. Although beams are relatively weak under these circumstances and post-standard injury rates will be high, pre-standard cars are even weaker and their injury rates will be disastrous. Indeed, this is the pattern that seems to develop in Table 10-11, when the injury rates in the struck vehicle are compared for large cars as the striking vehicle and light trucks. Although large cars and light trucks are of roughly equal weight, the injury rate in pre-standard cars is twice as high when a light truck is the striking vehicle.

Finally, when a bulky, massive vehicle such as a large truck or bus hits the side of a car, there will in most cases be contact over large parts of the car's side structure: pillars, roof rails, sills. The additional intrusion resistance provided by beams would be negligible under those circumstances, so a low injury reduction for Standard 214 would not be surprising. Moreover, when the striking vehicle is massive, only a small portion of its momentum is lost in the crash. Thus, the velocity of the occupant contact with the intruding door is only marginally greater than Delta V - regardless whether the door is soft or firm.

All of these explanations, however, should be considered tentative because the effectiveness differences in Table 10-11 are not significant and could be due to statistical coincidence.

10.5 Effectiveness as a function of accident, vehicle or occupant characteristics

The following analyses of NCSS and FARS generally do not reveal clear, significant differences in the effectiveness of Standard 214 across various accident, vehicle or occupant characteristics.

10.5.1 Serious injury reduction as a function of accident, vehicle or occupant characteristics

In Section 7.5, injury rates in pre- and post-Standard 214 cars were tabulated across control variables - accident, vehicle and occupant characteristics. In that section, the objective was to find the extent to which controlling for those variables would correct biases in the overall effectiveness estimates. Another use for those data is to calculate effectiveness of Standard 214 separately for each value of the control variable to see if it differs significantly from value to value.

Thirteen potential control variables were defined in Section 7.5.2. In this section, effectiveness is calculated across 9 of the 13. The 4 that are omitted are

- o size of striking vehicle - already covered in Section 10.4.3
- o nearside/farside - covered in Section 10.1
- o NCSS team - when the limited sample is subdivided seven ways, the effectiveness estimates would be statistically meaningless

- beam installation year - when the NCSS sample is split 7 ways, the results would be meaningless. In Section 10.5.2, effectiveness by installation year is calculated in FARS, which contains a much larger sample.

The remaining variables include 2 parameters describing the accident, 4 vehicle descriptors and 3 occupant descriptors. The list does not include PDOF, Delta V, extent of crush, etc. Since the values of these variables are themselves influenced by Standard 214, it is meaningless to compare the pre- and post-standard injury rates for a particular value of one of these variables (see Section 7.4.4 and Chapter 9).

Injury reductions for Standard 214 are calculated across each of the 9 remaining control variables, for single vehicle crashes, multivehicle crashes and nearside occupants in multivehicle compartment impacts. All pre-standard and post-standard cars on NCSS are used (no restriction of vehicle age range) in order to maximize the available sample size.

What level of difference in effectiveness values can be termed significant? The confidence bounds for the overall effectiveness of Standard 214 in single vehicle crashes, based on the full NCSS file, were 20-44 percent (see Table 7-20) - i.e., a tolerance of $\pm$ 12 percent, with one-sided $\alpha = .05$. If the file is split into two subfiles of equal size, a difference of 24 percent in the observed effectiveness of Standard 214 on the two subfiles would be significant with one-sided $\alpha = .05$. Since, in many of the cases that follow, there is no prior expectation of which value of the control variable should make Standard 214 more effective, it is best to use a two-sided test, further increasing the critical level of difference to about

30 percent. In other words, observed differences of effectiveness in single vehicle crashes are of no significance unless they are at least 30 percent. This is under the best case when the control variable splits the file equally. A larger difference must be found if one value of the control variable is more common than the other.

For multivehicle crashes, the critical difference is 25 percent. For nearside occupants in multivehicle compartment impacts it is 40 percent.

Moreover, if a significant difference is found in one type of crash (e.g., multivehicle), the result may be of questionable validity if not supported by similar trends in the other two types of crashes.

Thus, even though NCSS was large enough to provide statistically significant results on overall effectiveness, it is not large enough to investigate differences in effectiveness for various subgroups unless those differences are, in reality, large.

Table 10-12 shows the injury reduction for Standard 214 as a function of two accident parameters: urbanization and speed limit. Standard 214 was observed to reduce the risk of fatality or hospitalization by 4 percent in rural single-vehicle crashes; by 54 percent in urban single-vehicle crashes. Similarly, the observed effectiveness was 3 percent in single-vehicle crashes on 55 mph roads; 45 percent on lower-speed roads. The magnitude and consistency of these differences suggests that, perhaps, Standard 214 is more effective, in single vehicle crashes, in a lower-speed environment. If so, two explanations for the difference could be offered: (1) Standard 214 effectiveness in single-vehicle crashes decreases as crash severity increases;

TABLE 10-12

INJURY* REDUCTION FOR STANDARD 214 AS A FUNCTION OF ACCIDENT CHARACTERISTICS, NCSS

	Injury* Reduction for Standard 214 (%)		
	In Single Veh. Crashes	In Multiveh. Crashes	Nearside Occupants in Multiveh. Compartment Crashes
BY URBANIZATION			
Rural accidents	4	2	42
Urban accidents	54	17	24
BY SPEED LIMIT			
55 mph	3	26	40
Less than 55 mph	45	15	23

*Fatality or hospitalization

(2) A crash on a rural or high-speed road is more likely to involve a complex off-road excursion than a crash on an urban road - a crash mode where Standard 214 is not effective (see Section 10.4).

In multivehicle crashes, on the other hand, there is no significant evidence of differences in effectiveness. The magnitudes of the observed differences are well below the critical values. Moreover, the results are inconsistent: slightly higher effectiveness on urban accidents in all types of multivehicle crashes; in rural accidents in compartment crashes; higher effectiveness on 55 mph roads is inconsistent with higher effectiveness in urban accidents.

Table 10-13 shows effectiveness of Standard 214 as a function of 4 vehicle parameters: vehicle weight, type of B pillar, body structure and number of doors. There are no significant differences of effectiveness as a function of vehicle weight: observed effectiveness in single vehicle crashes is very slightly higher in heavy cars; in multivehicle crashes, light cars. Similarly, the type of B pillar (genuine hardtop vs. full B pillar) and body structure (body-and-frame vs. unitized) has neither a significant nor consistent impact on effectiveness.

Standard 214 does appear to be significantly more effective in single-vehicle crashes of 4 door cars (61%) than for 2 door cars (no change in the injury rate). If indeed, Standard 214 is more effective in 4 door cars, it could be explained as follows: two short beams, with a strong central post, may be more effective in deflecting fixed objects than one long beam. In multivehicle crashes, on the other hand, Standard 214 is observed to be slightly (not significantly) more effective in 2 door cars

TABLE 10-13

INJURY* REDUCTION FOR STANDARD 214 AS A FUNCTION OF THE STRUCK VEHICLE'S CHARACTERISTICS, NCSS

	Injury* Reduction for Standard 214 (%)		
	In Single Veh. Crashes	In Multiveh. Crashes	Nearside Occ. in Multivehicle Compartment Crashes
BY VEHICLE WEIGHT			
Less than 3500 pounds	25	14	29
3500 pounds or more	34	9	15
BY B-PILLAR TYPE			
Hardtop (no upper B-pillar)	15	31	34
Sedan, pillared hardtop (full B-Pillar)	31	9	15
BY BODY STRUCTURE			
Body and frame	47	18	25
Unitized or integral-stub frame	23	10	25
BY N OF DOORS			
2 doors	0	21	33
4 doors	61	3	25

*Fatality or hospitalization

than in 4 door cars. One explanation for the inconsistency would be that both effects (single and multi) are spurious. Another explanation is that the action of beams is different in multivehicle crashes: their primary effect is to resist intrusion, not deflect the striking vehicle (see Chapter 9). If so, the wider the door, the more vulnerable it is to an impact that does not involve pillars - thus beams might have more of an opportunity to resist intrusion on a 2 door car.

Table 10-14 shows effectiveness of Standard 214 as a function of 3 occupant parameters: belt usage, age and sex. There are so few belt users in NCSS and they are so rarely injured that the effectiveness values of Standard 214 for belt users are subject to extreme sampling error (i.e., ± 50-60 percent). Thus the comparisons of belt users and nonusers are subject to about twice as large a sampling error as other comparisons; they show no consistent trend.

The observed effectiveness of Standard 214 is quite similar for younger and older occupants and for males and females, suggesting no differences across these variables.

10.5.2 Fatality reduction as a function of beam installation year

In Section 6.6, a regression was performed on fatality rates per 1000 car years in order to estimate the overall effectiveness for Standard 214. The independent variables in the regression included BEAMS, whose regression coefficient was used to calculate the effectiveness of Standard 214 and T70, T70.5, T71, T72, T73 and T73.5 which flagged the model year in which beams were first installed. The same data set can be used to

TABLE 10-14

INJURY* REDUCTION FOR STANDARD 214 AS A FUNCTION OF OCCUPANT CHARACTERISTICS, NCSS

	Injury* Reduction for Standard 214 (%)		
	In Single Veh. Crashes	In Multiveh. Crashes	Nearside Occ. in Multiveh. Compartment Crashes
BY BELT USAGE			
Unrestrained occ.	22	14	19
Belt users (any type)	50	-34	68
BY OCCUPANT AGE			
Less than 25	32	20	27
25 or more	15	13	25
BY OCCUPANT SEX			
Male	30	16	22
Female	15	13	29

*Fatality or hospitalization

calculate separately the effectiveness of Standard 214 for each of the 7 groups of makes and models having the same initial installation year for beams - e.g., for full-sized GM cars, which got beams in 1969. This is done by adding, as independent variables in the regression, the interaction terms BEAMS x T70, ..., BEAMS x T73.5. Then the coefficient for BEAMS is used to calculate the effectiveness of Standard 214 for makes and models that got beams in 1969; the sum of the coefficients for BEAMS and BEAMS x T70 is used for models that got beams in 1970, etc.

The purpose of this analysis is twofold: to see if

(1) There is an age-related trend - i.e., if effectiveness uniformly increased (or decreased) for cars getting beams in later model years. A trend could indicate biases in the overall analysis procedure or a shift toward better (or worse) beams.

(2) There are significant differences in the effectiveness of Standard 214 between the specific models that constitute the 7 installation year groups.

Table 10-15 shows the observed effectiveness of Standard 214 in single vehicle crashes and for nearside occupants in multivehicle crashes for each of the 7 installation year groups. Obviously, there is no consistent trend from the top to the bottom of the table. Moreover, there are no significant differences across groups: the overall effectiveness estimate, according to Section 6.6 was accurate to about ± 10 percent. As a result, the estimates for individual groups are accurate to ± 20 - 50 percent depending on the size of the group (full-sized GM cars accounted

TABLE 10-15

FATALITY REDUCTION FOR STANDARD 214 AS A FUNCTION OF MODEL YEAR IN WHICH BEAMS WERE INSTALLED, FARS 1975-81

(Based on regression of fatality rates per 1000 vehicle years)

Beam Installation Year	Principal Makes/Models Involved	Fatality Reduction for Std. 214 (%) Single Veh. All Occ.	Multiveh. Nearside Occ.
1969	full-sized GM	3	1
1970	intermediate GM	14	4
mid 1970	Camaro - Firebird	26	16
1971	full-sized Ford & Mustang-Cougar	9	-22
1972	intermediate Ford	15	23
1973	compact GM & Ford, Pinto, most AMC	9	-10
mid 1973	most Chrysler, VW	7	-13

*For full list, see Table 4-1

for about 25 percent of the 1967-75 cars on the road; Camaro-Firebird for 4 percent). The variations of the estimates in Table 10-15 are easily within these limits. There is no basis for concluding that the beams installed in one type of car were more effective than those in other cars.

10.6 Summary

In single-vehicle side impacts, NCSS and FARS provide strong evidence that Standard 214 is effective in collisions with tall, massive fixed objects such as trees and poles and in collisions with guard rails (Sections 10.4.1 and 10.4.2). It is not effective in complex offroad excursions, collisions with moveable objects or noncollisions classified as side impacts. Standard 214 is beneficial for both nearside and farside occupants, but most of the benefits accrue to the nearside occupants (Sections 10.1 and 10.2.2 and 10.3). For nearside occupants, Standard 214 is most effective in preventing lower body injuries due to contact with a car's side interior surfaces; but there also appear to be noteworthy reductions of head and thoracic injuries due to contact with side surfaces, reduction of injuries due to contact with the car's frontal interior surfaces, and fewer ejections (Table 10-5). For farside occupants, Standard 214 is most effective in preventing ejection; there also appear to be moderate reductions of injuries due to contact with side surfaces and, perhaps, alleviation of frontal contact injuries. In short, for single-vehicle crashes, Standard 214 has not only accomplished its goal of reducing intrusion-related injuries (nearside occupants' lower body injuries due to side surface contacts) but also provided numerous other benefits which, especially in the case of fatalities, together exceed the benefits of the first accomplishment.

In multivehicle side impacts, Standard 214 is effective only when the impact is centered on the passenger compartment (Section 10.1). It does not appear to be effective in crashes that just peripherally damage the compartment. Standard 214 is likely to be effective in reducing ejection, but ejectees only constitute 5 percent of multivehicle side impact casualties (Table 10-6). For nearside occupants in compartment crashes, Standard 214 has substantially lessened the risk of lower body and thoracic injury due to contact with side interior surfaces; there appears to have been little or no effect on head injuries or on injuries due to contact with frontal surfaces (Section 10.2.3). For farside occupants, there may have been, at best, a moderate reduction of injuries due to contact with side surfaces. In short, for multivehicle crashes, Standard 214 has to a significant degree accomplished its goal of reducing intrusion related injuries (nearside occupants' lower body and thoracic injuries due to side surface contacts in compartment-centered impacts) but has provided few other benefits. As a result, the overall injury reduction for Standard 214 is considerably lower in multivehicle than in single vehicle crashes; and in the case of fatalities, where head injuries are of supreme importance, Standard 214 cannot be expected to have much effect in multivehicle crashes.

CHAPTER 11

THE ACTUAL COSTS AND BENEFITS OF STANDARD 214

One of the goals of the evaluation is to estimate the actual costs and actual benefits of Standard 214 in a manner that allows a meaningful comparison of costs and benefits.

The cost of Standard 214 is the average annual cost of the safety equipment which was actually installed in response to the standard in cars that are currently on the road (1982) - i.e. in cars of the past few model years. "Equipment installed in response to the standard" includes those items which were installed or modified in order to comply with the standard (sometimes, possibly, exceeding its minimum requirements) and other safety-related modifications in the side structure, if any, that were part of a simultaneous package with the preceding items. All costs are expressed in 1982 dollars.

Similarly, the benefits of Standard 214 are the fatalities and injuries that will be prevented annually in highway accidents, as a consequence of the safety modifications described above, when all cars meet the standard.

The analyses that follow estimate that the annual cost of Standard 214 is $610 million (which includes the cost of incremental lifetime fuel consumption) and the annual benefits are the prevention of 480 fatalities, 9500 nonfatal hospitalizations and 15,000 nonserious injuries.

11.1 The cost of Standard 214

The "cost of Standard 214" is defined as the net increase, due to equipment installed or modified in response to the standard, in the lifetime cost of owning and operating an automobile. There are two principal sources of increased cost: (1) The consumer price increase due to adding the equipment. (2) The lifetime increase in fuel consumption due to the incremental weight of the equipment.

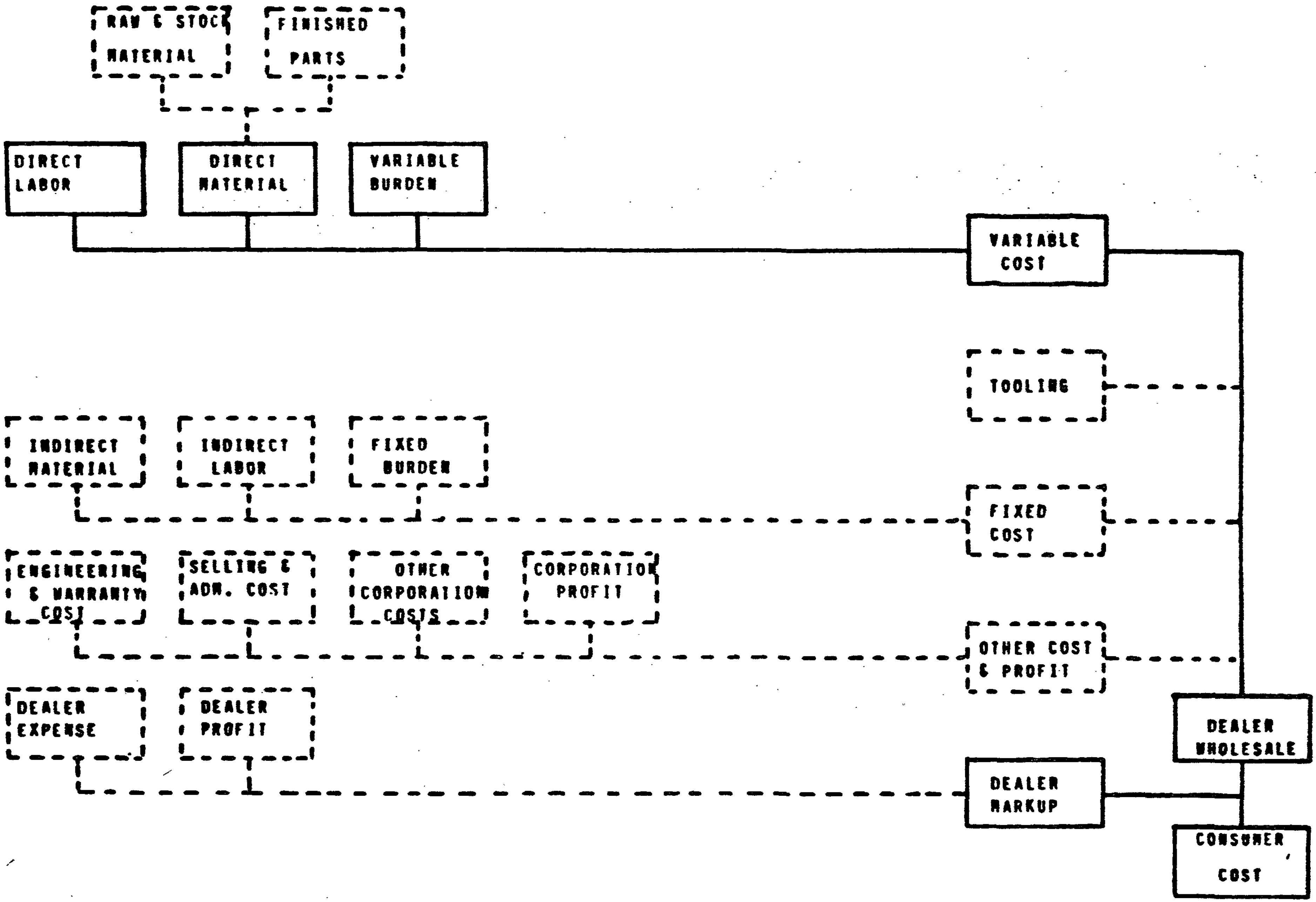
A procedure has been developed for estimating the cost and weight of equipment changes in response to NHTSA standards [56]. The procedure is based on component cost estimating techniques that are widely used in the automotive industry and it was used in all previous NHTSA evaluations of safety standards. It is illustrated in Figure 11-1.

The vehicle systems relevant to a standard are acquired, torn down and examined for a representative sample of post-standard cars and for corresponding pre-standard cars.

In the case of Standard 214, the principal change in vehicles that could be attributed to the standard was the installation of side door beams and their covers or pads, reinforcements and/or mounting flanges. Furthermore, Hedeen reports the addition of a "local reinforcement of the B pillar to the floor area" in full-sized General Motors cars at the time of beam installation [39]. In general, no other modifications of pillars door locks and hinges, sills, window frames or roof rails appear to have been performed - specifically, Hedeen stated pillars were not enlarged or strengthened (except locally at the floor area) and that door locks and hinges, (which had already been strengthened in model year 1965) did not require modification [39].

FIGURE 11-1
ELEMENTS OF CONSUMER COST

(Source: [38])



In fact, the major changes is side structures that took place during 1965-75, especially the shift from hardtops to pillared cars, were not necessary for meeting Standard 214 and were typically made at least 2 model years away from the year that beams were installed (see Section 4.4.3). The chief exceptions would appear to be the Camaro and Firebird, which got full B pillars simultaneous with beams and the Torino and Montego, which changed from unitized to body-and-frame construction in the year that beams were installed. It is most unlikely, however, that those changes were made for the purpose of securing compliance with the Standard or even as part of a safety package motivated by Standard 214. Therefore, those changes have not been included in "the cost of Standard 214."

Since the door beams and the lower pillar reinforcements are essentially "add-on" equipment that had no counterpart in pre-standard cars, no further detailed teardown of the pre-standard cars was needed.

The weights, materials, processing and finishing of individual components and the assembly method are established. The type, rough weight and finished weight of material is determined for each detail part, as well as the processing and assembly labor required, the scrap rate, machines and tooling utilized, the production quantity and the amortization period.

These data are first used to calculate the total weight and variable cost of each head restraint in the study sample. As Figure 11-1 shows, the variable cost includes direct material, direct labor and variable burden (see [38], pp. 4-5). Next, the tooling cost per car is determined by dividing the total expense for special tooling by the volume produced during the amortization period ([38], p. 8). The dealer's wholesale cost is determined by adding, to the above, the manufacturer's fixed costs per car (including indirect material and labor and fixed burden, as defined in [38], p. 7); other corporate costs such as engineering, selling and administration; and the manufacturer's profit (p. 8). The percentage amount of manufacturer's markups is determined by taking the corporate average, in recent years, for wholesale price relative to variable cost plus tooling (see [38], p. 6). Finally, dealer markups for expenses and profits are added to the wholesale price to obtain the consumer price. The percentage amount of dealer's markup is based on the overall average ratio of retail to wholesale price for the particular make and model under consideration (see [38], p. 9 and [56], pp. 9-11).

NHTSA contractors have performed cost analyses on <u>side door beam</u> assemblies (but not pillar-to-floor reinforcements) in a total of 46 cars [33], [34], [37], [56]. The cars date from model year 1973 to 1981 and include a representative mix of domestic and foreign manufacturers, size groups and 2 door/4 door models. For this evaluation, the most <u>recent</u> car in each manufacturer/size class has been selected, yielding a sample of 15 cars that are representative of automobiles sold in the United States during 1979-82.

Table 11-1 shows the cost (in 1982 dollars) and weight by side door beam assemblies, for each of the 15 cars, as estimated in [33], [34], [37], or [56]. Since the costs in [56] are stated in 1978 dollars and those in [37] are in 1979 dollars, they had to be inflated to 1982 prices by the use of the Consumer Price Index for automobiles. The index was 150.5 in model year 1978, 159.8 in 1979 and 197 in 1982. Thus, for example, the 1978 prices are inflated by 197/150.5.

TABLE 11-1

COST AND WEIGHT ADDED BY DOOR BEAMS

(1982 dollars)

Specimen Vehicle	1981 Sales of Similar Cars (000)	Door Beams Added Cost	Door Beams Added Weight
79 AMC Spirit 2dr	34	$30.94	33.33 pounds
81 Plymouth Reliant 4 dr	347	22.17	19.40
79 Ford Pinto 2 dr	378	23.51	24.42
79 Ford Fairmont 4 dr	233	31.89	21.58
75 Ford Granada 4 dr	154	39.06	22.70
80 Ford Thunderbird 2 dr	99	23.75	19.77
79 Ford LTD 4 dr	166	33.31	21.45
80 Chevrolet Citation 4 dr	692	24.24	22.52
79 Chevrolet Camaro 2 dr	147	34.89	41.25
78 Chevrolet Malibu 2 dr	1360	25.00	28.60
79 Chevrolet Caprice 4 dr	534	39.91	26.38
79 Oldsmobile Toronado 2 dr	141	34.48	38.88
79 Toyota Celica 2 dr	120	34.96	35.38
79 Toyota Corona 4 dr	22	35.32	25.74
79 Volkswagen Rabbit 2 dr	162	25.91	20.37
	SALES-WEIGHTED AVERAGE	$28.29	26.10 pounds

Table 11-1 shows the 1981 calendar year sales of cars of the same manufacturer/size category as the cars in the study sample. For example, 347,000 Plymouth Reliants and Dodge Aries were sold in 1981. The sales figure corresponding to Chevrolet Malibu includes sales of Monte Carlo, Grand Prix, Cutlass Supreme and Regal, which had nearly identical beams [37].

The sales-weighted averages of the 15 cost and weight estimates for side door beam assemblies are:

- o $28.29 (in 1982 dollars)
- o 26.10 pounds

No cost and weight estimates were obtained for the reinforcements of B pillars at the floor area in cars of the first model year with beams. A picture in Hedeen's paper of the reinforcements used in full-size 1969 GM cars suggests that they were a low cost item (relative to the side door beam assembly), probably costing less than $2 and weighing less than 2 pounds per car [39]. (NHTSA contractors did cost analyze B-pillar assemblies of 3 recent automobiles - 1980 Chevrolet Citation, 1980 Ford Thunderbird and 1981 Plymouth Reliant [33], [34]. Only the Citation contained reinforcements, which weighed 0.45 pounds and cost 57¢. However, by 1980-81, some of the strengthening required for Standard 214 might have been designed into the pillar itself, so the cost of the reinforcement might not indicate the full cost added by the standard.) It is assumed that the reinforcements illustrated in Hedeen's paper are typical of those initially used in other cars, that an equivalent cost and weight was designed into the pillars themselves if the reinforcements were dropped in subsequent redesigns, and that the full cost and weight of Standard 214 is the sum of the door beam assembly and these reinforcements. The average cost and weight per car for Standard 214 would then be approximately

- o $30 (in 1982 dollars)
- o 28 pounds

Each incremental pound of weight added to a car results in the consumption of an average of one additional gallon of fuel over the lifetime of a car [29], pp. VII-43-46. Table VII-16 of [29] calculates the discounted present value of consuming an additional gallon of fuel over the lifetime of a car. When the costs in that table are changed to reflect 1982 fuel prices ($1.32 per gallon in February), it is found that each incremental pound of weight adds $1.093 to the discounted lifetime cost of operating a car.

In other words, the average cost of Standard 214 is approximately

- o $61, lifetime per car.

Since an average of 10 million passenger cars are sold annually in the United States, the total cost of Standard 214 is about $610 million per year.

Secondary vehicle weight increases are sometimes needed to support the weight added to certain parts of a car by a safety device. The literature does not mention any secondary weight being added by Standard 214 - Hedeen specifically stating that a general beefing up of side structures was unnecessary. The preceding estimates of Standard 214 weight and cost already include an allowance of 2 pounds and $2 for local reinforcement or strengthening of pillars. Also, the beam is located near the center of the car and does not exert a large moment on the frame. For these reasons, secondary weight has not been included in the preceding calculations.

NHTSA's preliminary evaluation of Standard 214 estimated cost and weight increases of $30 (in 1977 dollars) and 36.1 pounds [46]. When these costs are inflated to 1982 dollars and 1982 fuel prices are used, those estimates correspond to a total lifetime cost of $87, which is $20 more than the estimate presented in this evaluation. There are 2 reasons for the change:

(1) The preliminary estimate was based on 1973 models; the current estimate, on more recent cars (1975-81). As a result of downsizing and some design simplifications, the real cost of Standard 214 has decreased.

(2) The preliminary estimate included very high costs and weights for GM intermediate-sized cars, which changed from hardtops to "colonnade" styling with massive B pillars in 1973. The incremental cost and weight of the B pillars was included in the preliminary evaluation and in the contractor's study [56]. Since, however, beams were installed in those cars 3 years before the B pillar change and since there is no evidence that the installation of massive B pillars was necessitated or motivated by Standard 214, their incremental cost and weight has not been counted in this evaluation.

On the other hand, this evaluation includes a cost and weight for reinforcements of B pillars at the floor level, which the preliminary estimate did not.

11.2 The benefits of Standard 214

In Chapters 6, 7, 8 and 10, the "best" estimates of Standard 214 effectiveness were:

o A 14 percent reduction of <u>fatalities</u> in single vehicle side impacts. (See Section 6.7. That estimate rises to 23 percent if noncollisions, grade-crossing accidents, etc. are not counted among the side impacts - see Section 10.4.1.)

o A 25 percent reduction of <u>fatalities and hospitalizations</u> in single vehicle side impacts (see Section 7.8).

o A 25 percent reduction of fatalities and hospitalizations for nearside occupants in multivehicle compartment impacts. (See Section 7.8. This amounts to an 8 percent overall reduction of fatalities and hospitalizations in multivehicle side impacts.)

o An 8 percent reduction of level "B" injuries in multivehicle side impacts (see Section 8.3).

The benefits of Standard 214 - the number of casualties that will be prevented annually when all cars meet the standard - is the product of these percentages and the numbers of casualties that <u>would</u> be occurring annually if <u>no</u> cars met the standard. The latter numbers, however, are unknown and must themselves be estimated from the same accident data.

The evaluation of energy absorbing steering columns presented analytic techniques for estimating, simultaneously, the benefits of a standard, the number of casualties that would be occurring if no cars met the standard, and confidence bounds for benefits ([44], pp. 184-187, 193-194 and 203-209). These techniques, with minor changes, also work for Standard 214.

11.2.1 Fatality reduction

The benefit of Standard 214 is the number of fatalities that the standard would have prevented in 1980 if all cars on the road were in compliance; 1980 is selected as the "base" year because it is the last year for which the Fatal Accident Reporting System contains complete data and also because there were no anomalous circumstances that made fatalities unusually high or low. The benefit is the difference of D^-, the number of automobile occupant deaths that would have occurred in single vehicle side impacts in 1980 if no cars had met Standard 214 and D^+, the number that would have happened if all cars had complied. Now:

$$D^- = f^- + \frac{f^+}{1-\varepsilon} + \frac{F_1}{f^- + f^+} f^0 + \frac{F_2}{F_2 + F_X} \frac{F_1}{f^- + f^+} F_0$$

where:

f^- = single vehicle side impact fatalities in pre-Standard 214 cars, FARS 1980 = 775

f^+ = single vehicle side impact fatalities in post-Standard 214 cars, FARS 1980 = 1974

ε = estimated effectiveness of Standard 214 (from Table 6-3) = .143

f^0 = single vehicle side impact fatalities in cars with unknown Standard 214 status, FARS 1980 = 161

$F_1 = f^- + \frac{f^+}{1-\varepsilon}$

F_X = automobile occupant fatalities in single vehicle crashes that are not side impacts, FARS 1980 = 10824

F_0 = automobile occupant fatalities in single vehicle crashes - unknown impact type, FARS 1980

= 390

$$F_2 = f^- + \frac{f+}{1-\varepsilon} + \frac{F_1}{f^- + f^+} f^0$$

Thus:

$D^- = 3360$ fatalities

$D^+ = (1-\varepsilon)\ D^- = 2880$

Benefits $= D^- - D^+ =$ 480 lives saved annually

Note that $D^- = 3360$ is also used in Section 3.1.1 as an estimate of the number of fatalities that would be occurring in single vehicle crashes in the absence of Standard 214.

Confidence bounds for the benefits and D^- can be obtained by noting that the effectiveness estimate ε is based on 7 years of FARS data (1975-81). Each individual year of FARS is a subsample of the data. In Section 6.3.3, the effectiveness was calculated separately for each year of FARS data; the results are shown in the left column of Table 11-2. Each of these effectiveness estimates ε_i can be used with the preceding formulas to obtain 7 individual estimates of D^- and Benefits. It is important to note that only the

TABLE 11-2

ESTIMATION OF BENEFITS OF STANDARD 214,

FOR 7 CALENDAR YEARS OF FARS DATA

Calendar Year of FARS	Observed effectiveness of Standard 214 $\mathcal{E}$		Estimates based on observed $\mathcal{E}$: D^-	Benefits
1975	.084		3194	268
1976	.204		3557	726
1977	.085		3197	272
1978	.026		3051	79
1979	.186		3496	651
1980	.205		3596	730
1981	.150		3380	507
		$\bar{X}$	3348	462
		S	203	246
		$S/\sqrt{7}$	77	93

values of ϵ are changed in making the estimates of D^- and benefits. The values of f^-, f^+, f^o, F_x and F_o are always the same census statistics from the 1980 FARS file - the objective being to estimate the number of fatalities that would have occurred in 1980. The 7 estimates of D^- and benefits are shown in the right columns of Table 11.2. The standard deviations s of the 7 estimates are also calculated and shown in the table.

A lower confidence bound for benefits (one-sided α = .05) is given by

$$\text{Benefits} - 1.943\ s(\text{benefits})/\sqrt{7}$$

$$= 480 - 1.943 \times 93 = 300 \text{ lives saved annually}$$

The upper bound is

$\text{Benefits} + 1.943\ s(\text{benefits})/\sqrt{7} = 660$ lives saved annually (Note that 1.943 is the 95th percentile of a t distribution with 6 df.)

The lower confidence bound for the number of fatalities that would have occurred in 1980 if no cars met Standard 214 is

$$D^- - 1.943\ s(D^-)/\sqrt{7}$$

$$= 3360 - 1.943 \times 77 = 3210 \text{ fatalities}$$

The upper bound is

$$D^- + 1.943\ s(D^-)/\sqrt{7} = 3510 \text{ fatalities}$$

These are the confidence bounds reported in Section 3.1.1.

11.2.2 Hospitalizations

The benefit of Standard 214 is the number of hospitalizations that the standard would have prevented in 1980 if all cars had been in compliance. The National Crash Severity Study data were collected in 1977-78, a period when accident conditions were reasonably similar to 1980. These benefits are calculated first for single vehicle crashes, then for nearside occupants in multivehicle compartment impacts and finally, for various other combinations.

The NCSS file contains n = 3267 (weighted) occupants of cars, involved in single-vehicle side impacts, for which the car's status with respect to Standard 214 could be identified. The multivariate model selected in Table 7-10 predicted that $y_* = 345.87$ of these persons would have been killed or hospitalized if all cars complied with Standard 214. The standard deviation of this estimate was $s_y = 14.25$. It predicted that $x_* = 518.12$ persons would have been killed or hospitalized if no cars met the standard; $s_x = 43.14$. In other words, the model attributed a 34 percent (1- 345.87/518.12) reduction in serious injuries to Standard 214.

The discussion in Chapter 7, however, indicated that the model may have failed to correct for certain biases in the injury rates, thereby over-predicting the effectiveness and the pre-standard injury rate. The "best" estimate for effectiveness was said to be 25 percent. Thus, a better estimate for the number of casualties if no cars meet the standard is given by

$$x_*' = \frac{y_*}{1 - .25} = 461.16$$

Although x_*' is not really a statistical estimate and a standard deviation, as such, cannot be calculated, it is intuitively reasonable to feel that x_*' has the same precision as x_*. Thus, $s_x = 43.14$ is used as the standard deviation of x_*' as well.

The benefits of Standard 214 are

$$B_1 = \left(\frac{x_*'}{n} - \frac{y_*}{n} \right) N \frac{1}{t}$$

where x_*', y_* and n were defined above,

N = U.S. number of automobile occupants in single-vehicle side impact towaways, 1980

t = fraction of hospitalizations occurring in towaways

and

$$N = n \frac{F}{f} \frac{P}{P_K} \frac{V}{V_K}$$

where

n = (weighted) NCSS occupants in single vehicle side impacts in cars with known Standard 214 status = 3267

F = automobile occupant fatalities on FARS 1980 = 27,442

f = automobile occupant fatalities on NCSS = 943

P = (unweighted) occupants on NCSS = 24,976

P_k = (unweighted) occupants on NCSS in cars with known crash modes = 19,856

V = (unweighted) cars in side impacts on NCSS = 5578

V_k = (unweighted) cars in side impacts on NCSS with known Standard 214 status = 5394

In other words, N is computed by multiplying each NCSS case by the ratio of FARS 1980 fatalities to NCSS fatalities and then adjusting this product for missing data on crash modes and Standard 214 status.

Finally,

$$t = \frac{1414}{1629}$$

which was the ratio of K + A injuries in towaways to all K + A injuries in Oakland County, Michigan, in 1973. This ratio was shown in the steering column evaluation ([44], p. 185) to apply to hospitalizations as well.

Thus, <u>benefits</u>,

$$B_1 = (x_*' - y_*) \frac{F}{f} \frac{P}{P_K} \frac{V}{V_K} \frac{1}{t}$$

$$= (461.16 - 345.87) \frac{27,442}{943} \frac{24,976}{19,856} \frac{5578}{5394} \frac{1629}{1414}$$

= <u>5028 fatalities and hospitalizations in single vehicle crashes</u> per year.

If <u>no</u> cars had complied with Standard 214 in 1980, these would have been

$$D_1 = x_*' \frac{F}{f} \frac{P}{P_K} \frac{V}{V_K} \frac{1}{t} \qquad = 20,100 \text{ fatalities and}$$

hospitalizations in single vehicle crashes. This is the estimate used in Section 3.1.2.

Confidence bounds for benefits can be obtained by noting that the relative variance is approximately

$$V^2(B_1) \cong \frac{S_x^2 + S_y^2}{(x_*' - y_*)^2} + \frac{1}{f} + \frac{P - P_K}{P P_K} + \frac{V - V_K}{V V_K} + \frac{1629 - 1414}{1629 \cdot 1414}$$

$$= .1553 + .0011 + \text{negl.} + \text{negl.} + .0001$$

$$= .1565$$

The standard deviation of B_1 is

$$s_{B_1} = \sqrt{.1565}\ B_1 = 1989$$

Note that the first term in $V^2(B_1)$ is derived from a t distribution with 9 df and the remaining terms are several orders of magnitude smaller. For all practical purposes, B_1 is derived from a t distribution with 9 df. The lower confidence bound for benefits in single vehicle crashes is

$$B_1 - 1.833\ s_{B_1} = 1382 \text{ fatalities and hospitalizations}$$

The upper bound is

$$B_1 + 1.822\ s_{B_1} = 8674 \text{ fatalities and hospitalizations}$$

Similarly, the relative variance of D_1^-, the number of casualties in 1980 if no cars meet the standard is

$$V^2(D_1^-) \cong \frac{s_x^2}{x_*^2} + \frac{1}{f} + \frac{P - P_K}{P P_K} + \frac{V - V_K}{V V_K} + \frac{1629 - 1414}{1629 \cdot 1414}$$

$$= .0088 + .0011 + \text{negl.} + \text{negl.} + .0001$$

$$= .01$$

Since

$$s_{D_1^-} = \sqrt{.01}\ D_1^- = 2010,$$

the lower confidence bound for D_1^- is

$$D_1^- - 1.833\ s_{D_1^-} = 16,400$$

and the upper bound is

$$\bar{D_1} + 1.833\, s_{\bar{D_1}} = 23{,}800$$

Those are the confidence bounds shown in Section 3.1.2.

The estimation process for nearside occupants in multivehicle compartment impacts is identical to the one for single vehicle crahses. The NCSS file contains 3152 (weighted) nearside occupants in multivehicle compartment impacts of cars with known Standard 214 status. The multivariate model selected in Table 7-16 predicted that $y_* = 338.40$ of these would have been killed or hospitalized if all cars had met Standard 214 - with standard deviation $s_y = 22.29$. It predicted $x_* = 479.96$ casualties if no cars had met Standard 214 - with $s_x = 45.91$. Again, other evidence presented in Chapter 7 suggested that the model overpredicted injuries in pre-standard cars and that the best estimate of effectiveness was 25 percent. Thus, a more suitable estimate of casualties if no cars meet Standard 214 is

$$x_*' = \frac{y_*}{1 - .25} = 451.20$$

The benefits are

$$B_2 = (x_*' - y_*) \frac{F}{f} \frac{P}{P_K} \frac{V}{V_K} \frac{1}{t}$$

$$= (451.2 - 338.4) \frac{27{,}442}{943} \frac{24{,}976}{19{,}856} \frac{5578}{5394} \frac{1629}{1414}$$

$$= 4919 \text{ fatalities and hospitalizations per year}$$

If no cars had complied with Standard 214 in 1980, there would have been

$$D_{2n}^{-} = x_{*}' \frac{F}{f} \frac{P}{P_K} \frac{V}{V_K} \frac{1}{t} = 19{,}700$$

fatalities and hospitalizations of nearside occupants in multivehicle compartment impacts. This is the estimate used in Section 3.1.2.

Confidence bounds for B_2 and D_{2n}^{-} are calculated by the same formulas as for single vehicle crashes, changing only the values of x_{*}', y_{*}, s_x and s_y.

$$S_{B_2} = 2232$$

and the confidence bounds for benefits are 828 to 9010.

$$S_{D_{2n}^{-}} = 2219$$

and the confidence bounds for D_{2n}^{-} are 15,800 to 23,600, as shown in Section 3.1.2.

The number of casualties that would have occurred in all types of multivehicle side impacts in 1980 if no cars had met Standard 214 is similarly calculated. The multivariate model in Table 7-13 yielded predictions of $y_{*} = 1129.42$, $s_y = 45.23$, $x_{*} = 1293.87$, $s_x = 53.79$. The "best" estimate of effectiveness in all types of multivehicle crashes, however, was 8 percent. Thus, a more suitable estimate of casualties on NCSS if no cars meet Standard 214 is

$$x_{*}' = \frac{y_{*}}{1 - .08} = 1227.63$$

If no cars had complied with Standard 214 in 1980, there would have been

$$D_2^- = 1227.63 \; \frac{F}{f} \; \frac{P}{P_\alpha} \; \frac{V}{V_\alpha} \; \frac{1}{t} \qquad = 53,500$$

fatalities and hospitalizations in <u>all</u> types of multivehicle side impacts, as shown in Section 3.1.2.

$$S_{D_2^-} = 2981$$

and the confidence bounds for D_2^- are 48,100 - 59,000.

Finally, the <u>benefits</u> for <u>single and multivehicle</u> crashes, combined, are

$$B = B_1 + B_2 = 5028 + 4919 = \underline{9947 \text{ fatalities and hospitalizations}}$$

The standard deviation is

$$S_B = (S_{B_1}^2 + S_{B_2}^2)^{1/2}$$

$$= (1989^2 + 2232^2)^{1/2} = 2990$$

The estimates for single and multivehicle crashes are essentially independent from one another and are derived from t distributions with 9 df. The combined benefits, which are the sum of the two estimates, are derived from a t distribution with degrees of freedom:

$$df = S_B^4/(S_{B_1}^4/9 + S_{B_2}^4/9) = 17$$

Therefore, the confidence bounds for benefits are

$B \pm 1.74\ S_B$ = 4744 to 15150 fatalities and hospitalizations where 1.74 is the 95th percentile of a t distribution with 17 df.

In Section 11.2.1 it was shown that Standard 214 saves 480 lives per year. An estimate of the nonfatal hospitalizations eliminated by Standard 214 is obtained by subtracting 480 from the above benefits. Thus, Standard 214 eliminates 9467 nonfatal hospitalizations per year (confidence bounds 4264 to 14,670).

The number of casualties that would have occurred in single and multivehicle crashes, combined, in 1980 if no cars had met Standard 214 is

$D^- = D_1^- + D_2^- = 20{,}100 + 53{,}500 =$ 73,600 fatalities and hospitalizations.

The standard deviation is

$$S_D = (S_{D_1^-}^{\ 2} + S_{D_2^-}^{\ 2})^{1/2}$$
$$= (2011^2 + 2981^2)^{1/2} = 3596$$

This sum of essentially independent t distributions, with 9 df each, has degrees of freedom

$$df = S_{D^-}^{\ 4} / (S_{D_1^-}^{\ 4}/9 + S_{D_2^-}^{\ 4}/9) = 15$$

Therefore, the confidence bounds for overall casualties are

$D^- \pm 1.753\ S_D$ = 67,300 - 80,000 fatalities and hospitalizations where 1.753 is the 95th percentile of a t distribution with 15 df. These are the values shown in Section 3.1.2.

11.2.3 Nonserious injuries

It was shown in Chapter 8 that Standard 214 significantly reduced K, A and B level injuries in multivehicle side impacts in Texas. Moreover, the reduction appeared to be of roughly the same magnitude as the reduction of hospitalizations in NCSS.

In the preceding section, it was estimated that Standard 214 eliminates 4919 hospitalizations per year in multivehicle crashes. Hospitalizations and level "K or A" injuries are about equally common. Table 8-2 shows that there were exactly 3 times as many level "B" injuries in Texas multivehicle side impacts of pre-Standard 214 cars as there were "K or A." Since level B injuries are 3 times as common as hospitalizations and Standard 214 is about equally effective for both types of injuries, the standard should eliminate about 3 times as many B injuries as hospitalizations - i.e., about 14,800 B injuries per year in multivehicle crashes.

This should be considered a rough estimate. No confidence bounds have been calculated. It would have been possible to develop relatively narrow statistical confidence bounds based on the sampling error of the Texas results (see Table 8-2), but they would have understated the actual uncertainty inherent in estimating a national total from the data of a single State.

1.2.4 Summary of benefits

Table 11-3 summarizes the benefits of Standard 214 and their confidence bounds, as estimated in Sections 11.2.1 - 11.2.3.

11.3 Cost-effectiveness

A method to assess the cost-effectiveness of a standard that saves lives and prevents serious injuries was developed in NHTSA's evaluation of energy-absorbing steering assemblies [44], pp. 211-214.

The benefits of a standard are expressed in Equivalent Fatality Units (EFU). Each life saved is a benefit of 1 EFU. Each person who avoids nonfatal hospitalization is assigned a benefit of 0.0592 EFU. This assignment is based on a recent assessment of average cost of the injuries of persons who were hospitalized after a crash. (Note that the steering column evaluation assigned a benefit of 0.05 EFU per contact source that caused an injury requiring hospitalization [44], p. 212. The figure of .0592 used here differs from the steering column evaluation because it is the benefit per hospitalization eliminated, not per contact source of hospitalizing injury. Also, it is based on more recent injury cost data.) The sum of the annual benefits, expressed in EFU, is divided by the total annual cost. The number of EFU eliminated per million dollars of cost is a single figure that expresses the cost effectiveness of a standard that saves lives and prevents serious injuries. It allows a direct comparison with other standards that also save lives and prevent serious injuries, but in varying proportions.

Standard 214 is estimated to save 480 lives per year (see Table 11-3); this is a contribution of 480 EFU. It eliminates an estimated 9467 nonfatal

TABLE 11-3

ANNUAL BENEFITS OF STANDARD 214

	Best Estimate	Standard Deviation	Degrees of Freedom	Confidence Bounds*
LIVES SAVED				
In single-vehicle crashes	480	93	6	300 to 660
NONFATAL HOSPITALIZATIONS ELIMINATED				
In single-vehicle crashes	4548	1989	9	902 to 8194
In multivehicle crashes	4919	2232	9	828 to 9010
Subtotal	9467	2990	17	4264 to 14670
"B" LEVEL INJURIES ELIMINATED				
In multivehicle crashes	14,800	--	--	--

*One-sided $\alpha = .05$

hospitalizations; each of these contributes 0.0592 EFU, so this is a contribution of 560 EFU. Thus, the total benefits of Standard 214 are <u>1040 EFU</u>. (Table 11-3 also indicates that Standard 214 eliminates 14,800 nonserious injuries, but that benefit has not been counted in the calculation of EFU. Similarly, in the evaluation of head restraints, minor injuries were not expressed in EFU [45], pp. 245-250.)

In Section 11.1, the annual cost of Standard 214 was estimated to be $610 million. Since the standard eliminates 1040 EFU and costs $610 million, the <u>cost-effectiveness</u> is

$$\frac{1040}{610} = \underline{1.7 \text{ EFU per million dollars}}$$

Confidence bounds for cost-effectiveness are calculated as follows: the number of EFU eliminated by Standard 214 is the sum of the benefits in fatal and nonfatal injuries. Each of these benefits is an estimate derived from a t distribution. From Table 11-3:

b_f = lives saved = 480

b_n = nonfatal hospitalizations prevented = 9467

b = benefits in EFU = $b_f + 0.0592\ b_n = 1040$

s_f = std. dev. of b_f = 93

d_f = df for estimate of b_f = 6

s_n = std. dev. of b_n = 2990

d_n = df for estimate of b_n = 17

Now let

s = standard deviation of b

$$= (s_f^{\,2} + (.0592\ s_n)^2)^{1/2} = 200$$

d = degrees of freedom for b

$$= s^4/\ (s_f{}^4/d_f + (.0592\ s_n)^4/d_n) = 22$$

Thus, the total benefits of Standard 214, expressed in EFU, are derived from a t distribution with 22 df. A lower confidence bound for benefits (one-sided $\alpha = .05$) is given by

$$b - 1.717\ s = 696 \text{ EFU},$$

where 1.717 is the 95th percentile of a t distribution with 22 df. The upper bound is

$$b + 1.717\ s = 1384 \text{ EFU}$$

The lower confidence bound for cost-effectiveness is

$$\frac{696}{610} = 1.14 \text{ EFU per million dollars}$$

The upper bound is

$$\frac{1384}{610} = 2.27 \text{ EFU per million dollars}$$

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